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Proceedings of the Non-Linear Aero Prediction Requirements Workshop

Edited by
Michael J. Logan
Langley Research Center • Hampton, Virginia

163P

(NASA-CP-10138) PROCEEDINGS OF THE NON-LINEAR AERO PREDICTION REQUIREMENTS WORKSHOP (NASA) 163 p

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Proceedings of a workshop sponsored by the National Aeronautics and Space Administration, Washington, D.C., and held at Langley Research Center, Hampton, Virginia
December 8–9, 1993

National Aeronautics and Space Administration
Langley Research Center • Hampton, Virginia 23681-0001

March 1994

PREFACE

The purpose of the Non-Linear Aero Prediction Requirements Workshop, held at NASA Langley Research Center December 8-9, 1993, was to identify and articulate requirements for non-linear aero prediction capabilities during conceptual/preliminary design. The attendees included engineers from industry, government, and academia in a variety of aerospace disciplines such as advanced design, aerodynamic performance analysis, aero methods development, flight controls, experimental and theoretical aerodynamics. The conference consisted of several presentations by industry and government organizations followed by panel discussions. This report contains the hard copies of the presentations made, and presents the results of the panel discussions. Also included is additional information provided by invitees who were unable to attend.

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FIGHTER/ATTACK AIRCRAFT GROUP

NON-LINEAR AERO PREDICTION REQUIREMENTS WORKSHOP

DECEMBER 8-9 1993

Michael J. Logan, P.E.
Group Leader, Fighter/Attack Aircraft Group
Vehicle Integration Branch
Advanced Vehicles Division
NASA Langley Research Center

FIGHTER/ATTACK AIRCRAFT GROUP

NON-LINEAR AERO PREDICTION REQUIREMENTS WORKSHOP

AGENDA - Wednesday Dec. 8

OPENING REMARKS - Mike Logan, NASA

CURRENT METHODS - Mark Guynn, NASA

INDUSTRY/GOVERNMENT NEEDS BRIEFS

PANEL DISCUSSIONS

FIGHTER/ATTACK AIRCRAFT GROUP

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NON-LINEAR AERO PREDICTION REQUIREMENTS WORKSHOP

AGENDA - Thursday, Dec. 9

INDUSTRY DATA BASE NEEDS REVIEWS

PANEL DISCUSSION - DATA BASE

PANEL DISCUSSION - VALIDATION

COLLECT MATERIALS & ADJOURN

NON-LINEAR AERO METHODS

TOPICS

AERO METHODS HISTORY

PROJECT IMPETUS

PROJECT DEFINITION

PROPOSED APPROACH

INPUT TO PLANS/RECOMMENDATIONS

FIGHTER/ATTACK AIRCRAFT GROUP

NON-LINEAR AERO METHODS

BRIEF METHODS HISTORY

"PRE-COMPUTER" PREDICTION - (< '60s)

- ANALYTICALLY BASED - MASSIVE HAND CALCULATIONS AT A DETAIL LEVEL
- TRANSITIONED TO DATCOM HANDBOOKS LATE '60s
- MOSTLY BRUTE FORCE FOLLOWED BY TESTING

"EARLY" COMPUTER PREDICTION (< '80s)

- IMPLEMENTATION OF DATCOM HANDBOOK METHODS
- TRANSITION TO LINEAR & POTENTIAL METHODS

"CFD" ERA (80's - present)

- SWALLOWED VIRTUALLY ALL RESOURCES

FIGHTER/ATTACK AIRCRAFT GROUP

NON-LINEAR AERO METHODS

PROJECT DESCRIPTION

OBJECTIVE:

TO DEVELOP METHODOLOGY FOR ACCURATE AERODYNAMIC PARAMETERS (INCLUDING HIGH AOA) PREDICTION DURING CONCEPTUAL DESIGN

APPROACH: (PRELIM.)

IDENTIFY/ASSESS CURRENTLY AVAILABLE METHODS
CONDUCT REQUIREMENTS SURVEY
DEVELOP METHODOLOGY AND IMPLEMENTATION APPROACH
DEVELOP AND VALIDATE METHODLOGY

ANTICIPATED RESULTS:

PREDICTIIVE METHOLODOLOGY
VALIDATION DATA BASE
DOCUMENATION AND "TECH TRANSFER"

Advanced Vehicles Division

FIGHTER/ATTACK AIRCRAFT GROUP

NON-LINEAR AERO METHODS

PROJECT IMPETUS

AGILITY DESIGN STUDY

- IN-HOUSE CONFIGURATION DEVELOPMENT
- AGILITY METRIC PREDICTION
- AIRFRAMER STUDIES RESULTS

METHODOLOGY ACQUISTION

- ASSUMED METHODS WERE AVAILABLE
- IDENTIFIED AND ACQUIRED SEVERAL
- NONE WERE FOUND GENERALLY APPLICABLE

REQUESTS FROM INDUSTRY

- WERE UNABLE TO RESPOND ADEQUATELY

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NON-LINEAR AERO METHODS

PROPOSED APPROACH

METHODOLOGY EVALUATION

- NUMEROUS METHODS EVALUATED
- SOME METHODS ENHANCEMENTS MADE

PREDICTION REQUIREMENTS MEETING:

- INTENDED AS GOVERNMENT-INDUSTRY-ACEDEMIA
- MEETING INTENDED TO DEFINE REQUIREMENTS FOR METHOD & DATA BASE
- PLANNED FOR DECEMBER 8-9, 1993

Advanced Vehicles Division

FIGHTER/ATTACK AIRCRAFT GROUP

NON-LINEAR AERO METHODS

PROPOSED APPROACH (Cont'd)

DETAILED REQUIREMENTS TO BE ISSUED:

- USING INPUTS FROM REQUIREMENTS WORKSHOP
- DRAFT ISSUED FOR COMMENT THEN MADE INTO NASA PUBLICATION

DEVELOPMENT APPROACH GROUP:

- INTENDED AS GOVERNMENT-INDUSTRY CONSORTIUM
- CO-LOCATED AT LaRC (?), FUNDED BY NASA, SHORT DURATION
- WOULD DEVELOP APPROACH, SCHEDULE, AND RESOURCE REQUIREMENTS

FIGHTER/ATTACK AIRCRAFT GROUP

NON-LINEAR AERO METHODS

PROPOSED APPROACH (Cont'd)

METHODOLOGY DEVELOPMENT GROUP:

- A GOVERNMENT-INDUSTRY-ACEDEMIA CONSORTIUM
- CO-LOCATED AT LaRC, FUNDED BY NASA
- WOULD DEVELOP AND VALIDATE METHODOLOGY

CONCURRENT ACTIVITIES:

- DATA BASE FORMULATION & RETRIEVAL METHODS
- DATA BASE ACQUSITION AND CATALOGING
- EXPERIMENTAL/FLIGHT TEST DATA BASE EXPANSION
- VALIDATION PREPARATION

FIGHTER/ATTACK AIRCRAFT GROUP

NON-LINEAR AERO METHODS

SUMMARY

ADVANCED DESIGN AERO PREDICTION

- STATE-OF-THE-ART INSUFFICIENT
- TEST DATA IS RANDOMLY DISTRIBUTED
- STRONG NEED WITHIN INDUSTRY/GOVERNMENT

DEVELOPMENT PROJECT

- REQUIRES CO-OPERATIVE INDUSTRY-WIDE EFFORT
- NEEDS CLEARLY ARTICULATED GOALS & SCHEDULES
- MAY NEED EXPERIMENTAL/FLIGHT TESTING
- FIRST STEPS UNDERWAY

CURRENT CAPABILITIES FOR PREDICTION OF HIGH-ANGLE-OF-ATTACK AERODYNAMICS DURING CONCEPTUAL DESIGN

Mark D. Guynn, NASA Langley

Non-Linear Aerodynamics Prediction Requirements Workshop
NASA Langley Research Center
December 8–9, 1993

HIGH-ANGLE-OF-ATTACK AERO PREDICTIONS

- BACKGROUND
- DESCRIPTION OF CODES EVALUATED
- COMPARISONS WITH EXPERIMENTAL DATA
- GENERAL COMMENTS
- CONCLUSIONS
- RECOMMENDATIONS

HIGH-ANGLE-OF-ATTACK AERO PREDICTIONS

Evolution of Review

- Agility Assessment Requires Knowledge of S&C at High α
- Only Experience With Digital DATCOM
- Search For Codes With High α Capabilities
- Promising Codes Selected For Evaluation

DESCRIPTION OF CODES

Codes Selected for Evaluation

- **Digital DATCOM**
- **VORSTAB II**
- **HASC**
- **APAS** (Reference Linear Code)

DESCRIPTION OF CODES

Digital DATCOM: Predicts static stability, high lift and control, and dynamic derivatives using methods contained in USAF S&C DATCOM

Development: McDonnell Douglas Astronautics

Methodology: Semi–Empirical, based on basic geometric parameters

Addressable Configurations: 2 panel lifting surfaces, slats/flaps, elliptical bodies, traditional layouts

DESCRIPTION OF CODES

Digital DATCOM (Continued)

Output: C_L, C_M, C_D, $C_{Y\beta}$, $C_{n\beta}$, $C_{l\beta}$, C_{Lq}, C_{Mq}, $C_{L\alpha}$, $C_{M\alpha}$, C_{l_p}, C_{Y_p}, C_{n_p}, C_{n_r}, C_{l_r}, Increments due to high–lift and flap devices

Geometry Input: Surfaces – span, sweep, chord
Bodies – radius, area, perimeter, camber

Limitations: Unconventional layouts
$C_{Y\beta}$, $C_{n\beta}$, constant with α
Flap effectiveness constant with α

DESCRIPTION OF CODES

VORSTAB II: Predicts longitudinal and lateral/directional aerodynamic characteristics for configurations influenced by vortex effects

Development: Vigyan Research Associates/
University of Kansas

Methodology: Lifting Surface – Vortex Lattice +
Suction Analogy or Free Vortex Filament
Forebody – Slender Body Theory

Addressable Configurations: Up to 6 lifting surfaces, LE & TE Flaps,
Fuselage w/ noncircular cross–sections

DESCRIPTION OF CODES

VORSTAB II (Continued)

Output: C_L, C_M, C_D, C_{Y_β}, C_{n_β}, C_{l_β}, C_{l_p}, C_{Y_p}, C_{n_p},
C_{n_r}, C_{Y_r}, C_{l_r}

Geometry Input: Surfaces – vortex lattice type panels
Bodies – elliptical: radius
arbitrary: polar (r,θ)

Limitations: No longitudinal dynamic derivatives
Requires flow information in addition to geometry

DESCRIPTION OF CODES

HASC: Combination of 3 Codes (VORLAX, VORLIF, VTXCLD) to predict stability parameters at high angle of attack

Development: Lockheed Aeronautical Systems

Methodology: VORLAX – Vortex lattice method
VORLIF – Semi–empirical, predicts vortex effects on surfaces
VTXCLD – 2D, unsteady separated flow analogy for smooth bodies

Addressable Configurations: Configurations that can be accurately represented by flat quadrilateral panels (+twist and camber), Elliptical forebody

DESCRIPTION OF CODES

HASC (Continued)

Output: C_X, C_Y, C_Z, C_{MX}, C_{MY}, C_{MZ} for body, wind, and stability axes

Geometry Input: Surfaces and bodies represented by 2D panels

Limitations: Limited interaction between components
Forebodies of arbitrary cross–section

DESCRIPTION OF CODES

APAS: Aerodynamic analysis system which predicts static, rotary, and control longitudinal and lateral characteristics

Development: Rockwell International

Methodology: Surfaces – Source & Vortex Panels
+ LE Suction Effects
Bodies – Slender Body Theory
+ "Interference Shell"

Addressable Configurations: 3D configurations, nonplanar surfaces of arbitrary planform, bodies with non–circular cross–sections

DESCRIPTION OF CODES

APAS (Continued)

Output: C_L, C_M, C_D, C_Y, C_n, C_l

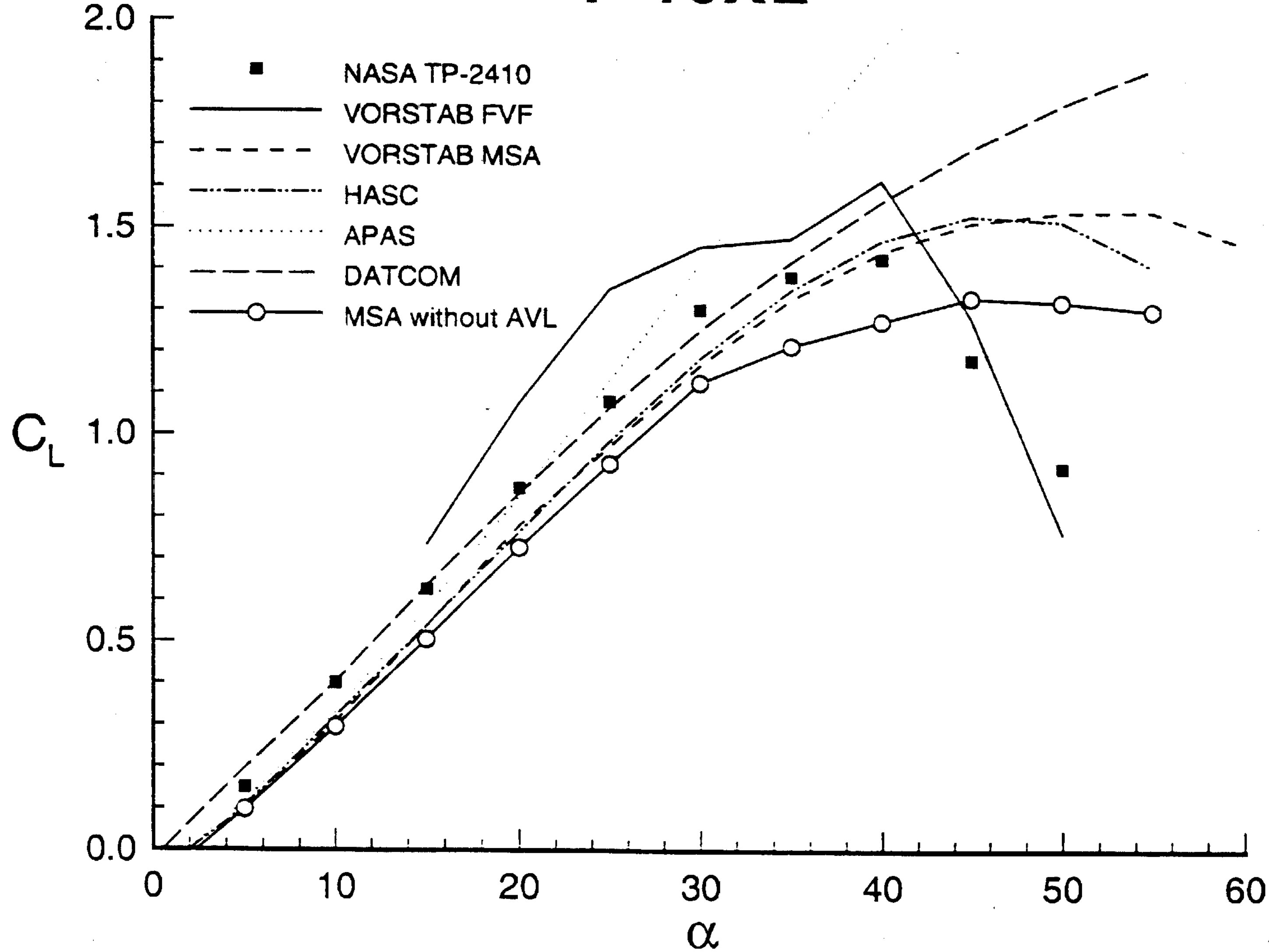
Geometry Input: Surfaces and bodies described by stacked parallel cross–sections (interactive graphical interface)

Limitations: No corrections for high α effects

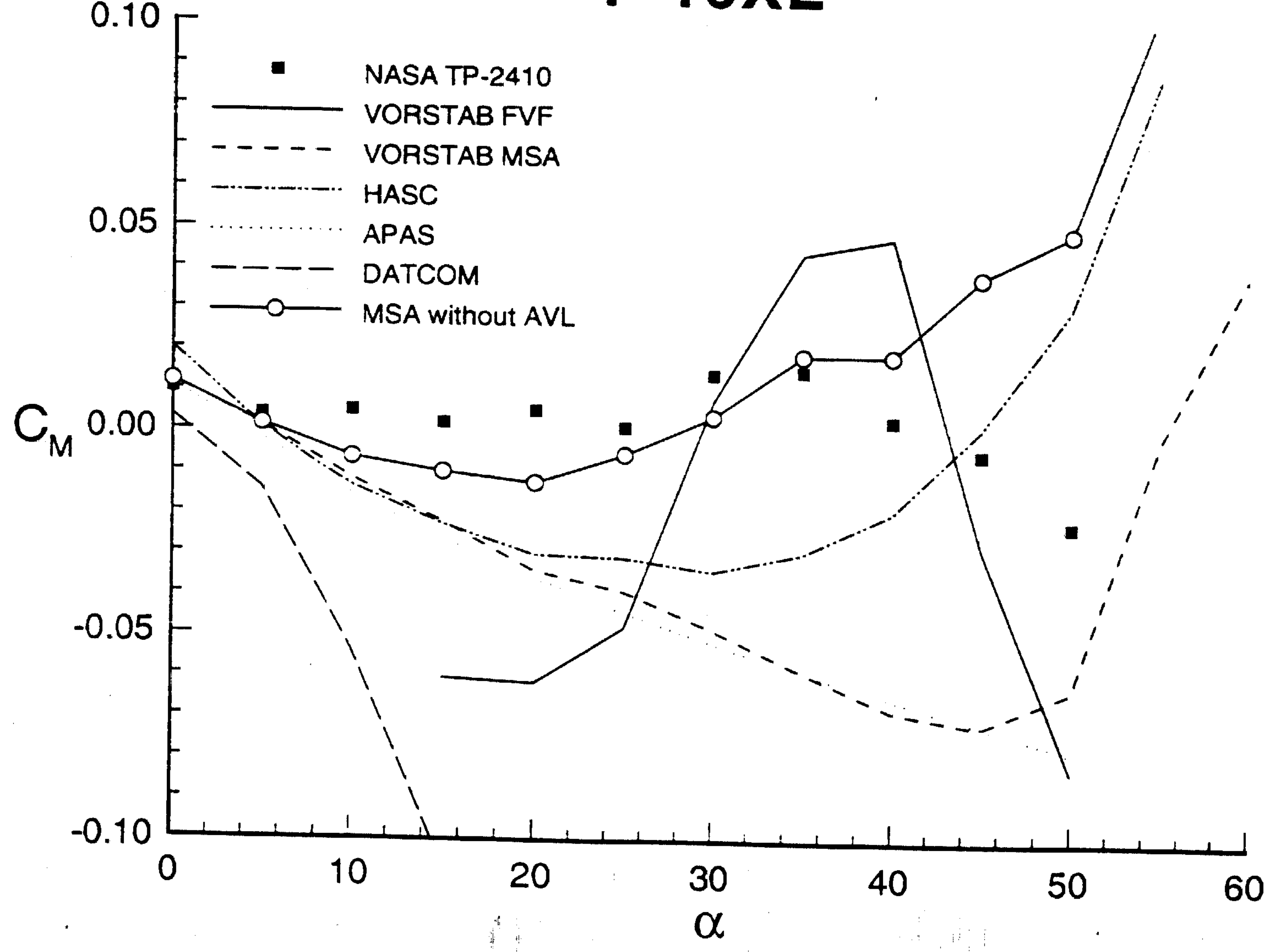
COMPARISON OF RESULTS

- Configurations Selected For Analysis
  - F–16XL
  - F–18 (Limited Evaluation)
- Comparisons to Low Speed Wind Tunnel Data
  - F–16XL: 18% Model, Langley 30x60, NASA TP–2410
  - F–18: 16% Model, Langley 30x60, NASA CP–3149
- Characteristics Compared
  - Longitudinal: (C_L, C_M) vs. α; C_D vs. C_L; L/D vs. C_L; ΔC_M
  - Lateral: $(C_{Y_\beta}, C_{n_\beta}, C_{l_\beta}, C_{l_p}, C_{n_r})$ vs. α

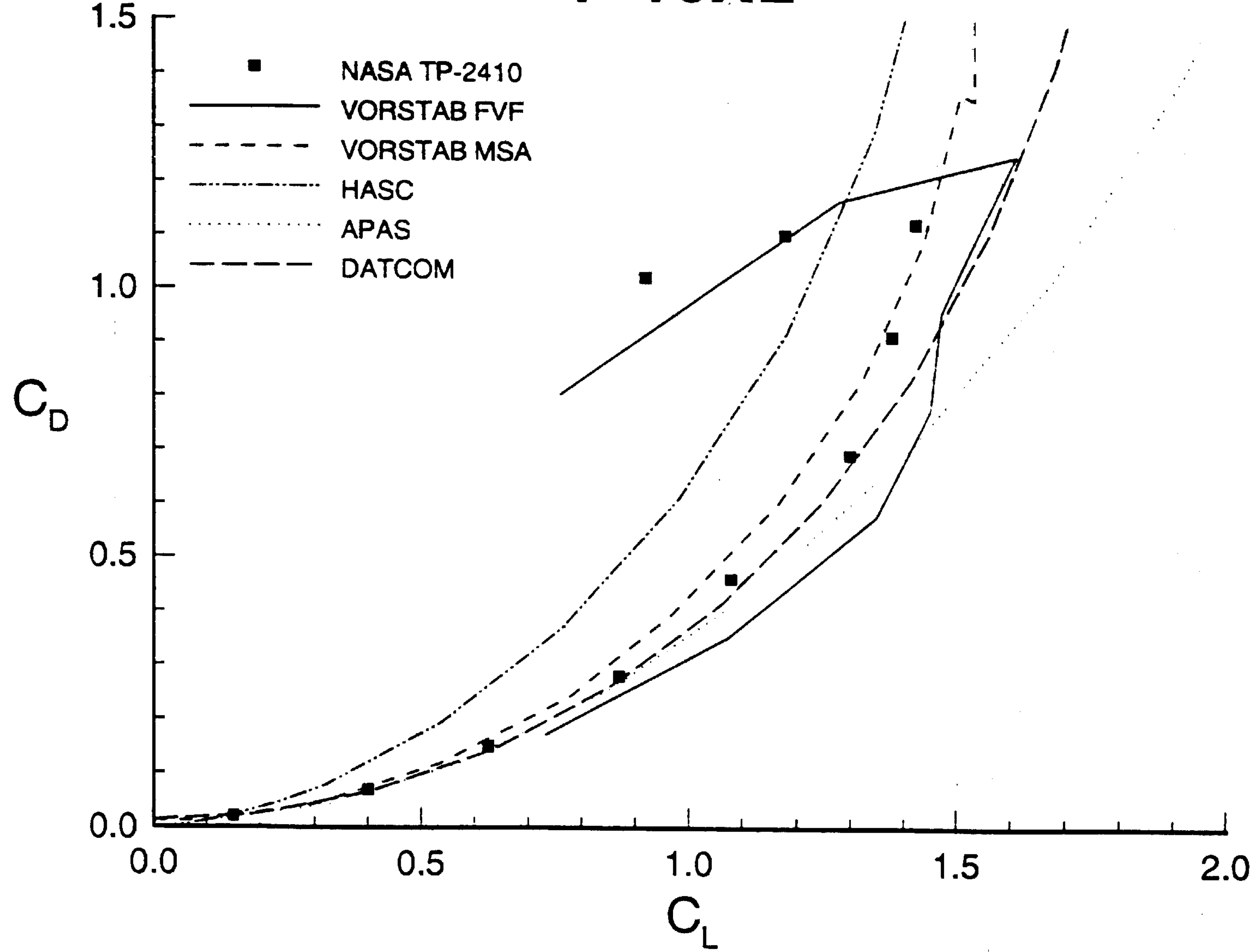
COMPARISON OF RESULTS
F-16XL



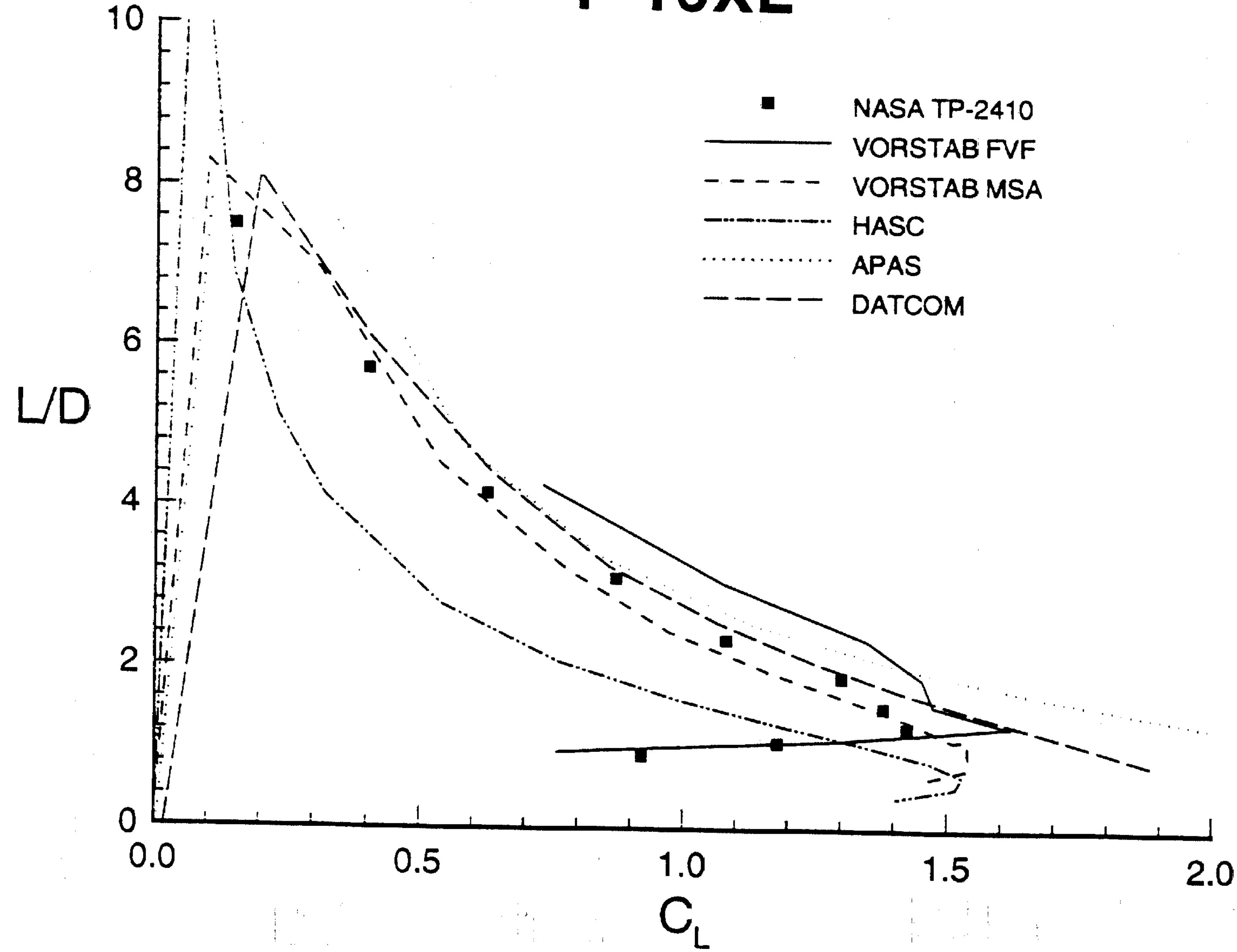
COMPARISON OF RESULTS
F-16XL



COMPARISON OF RESULTS
F-16XL



COMPARISON OF RESULTS
F-16XL



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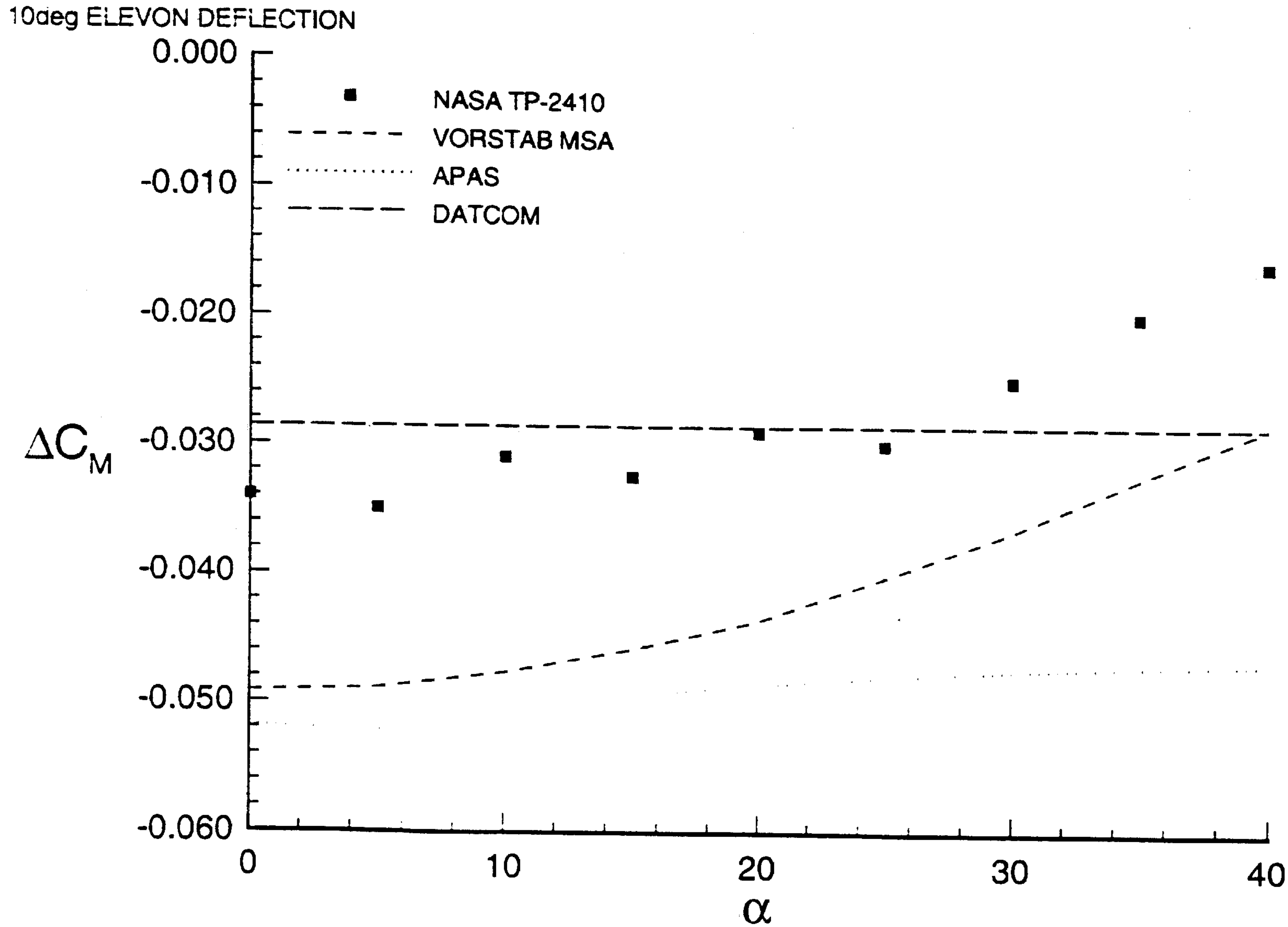

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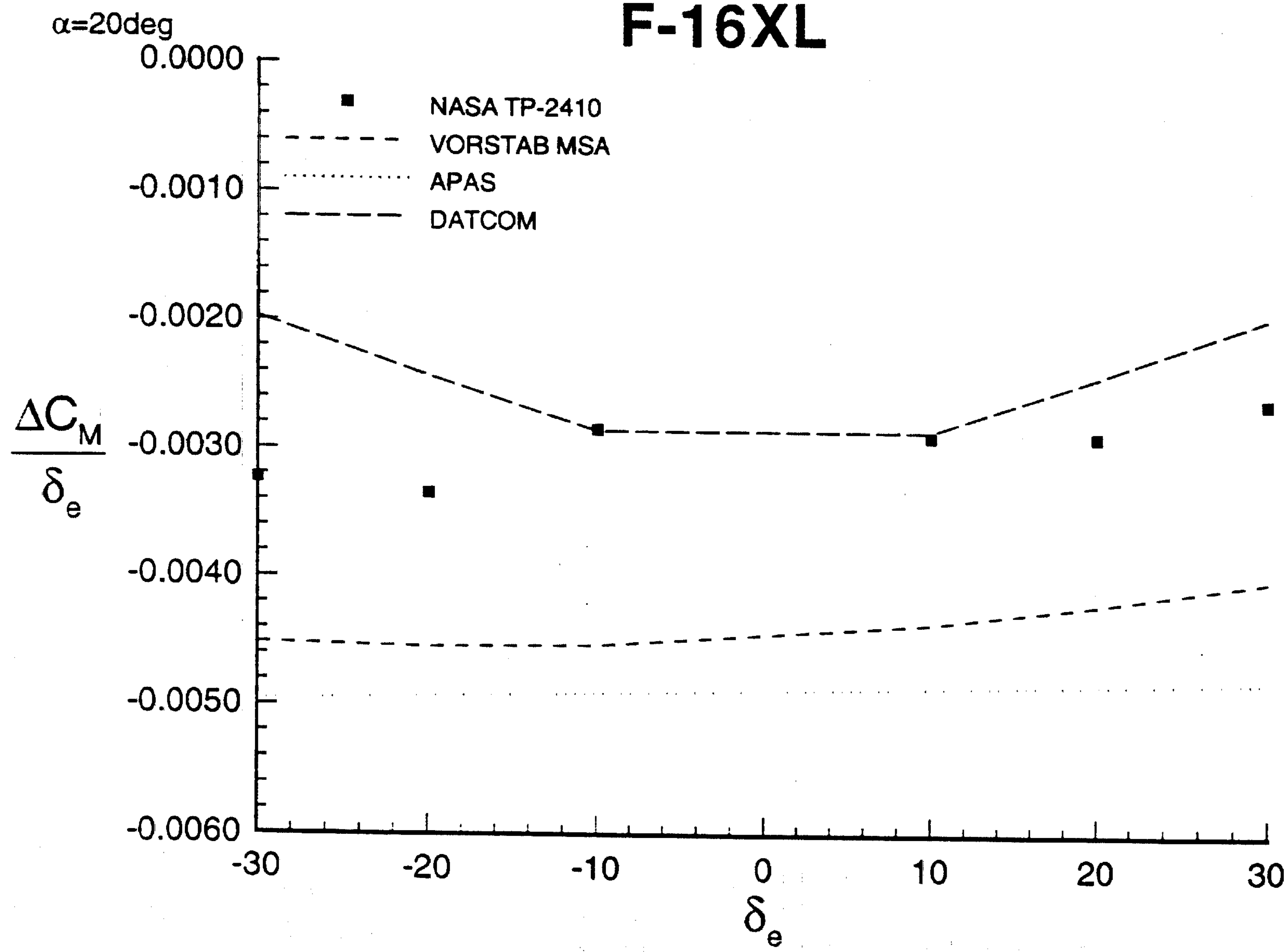


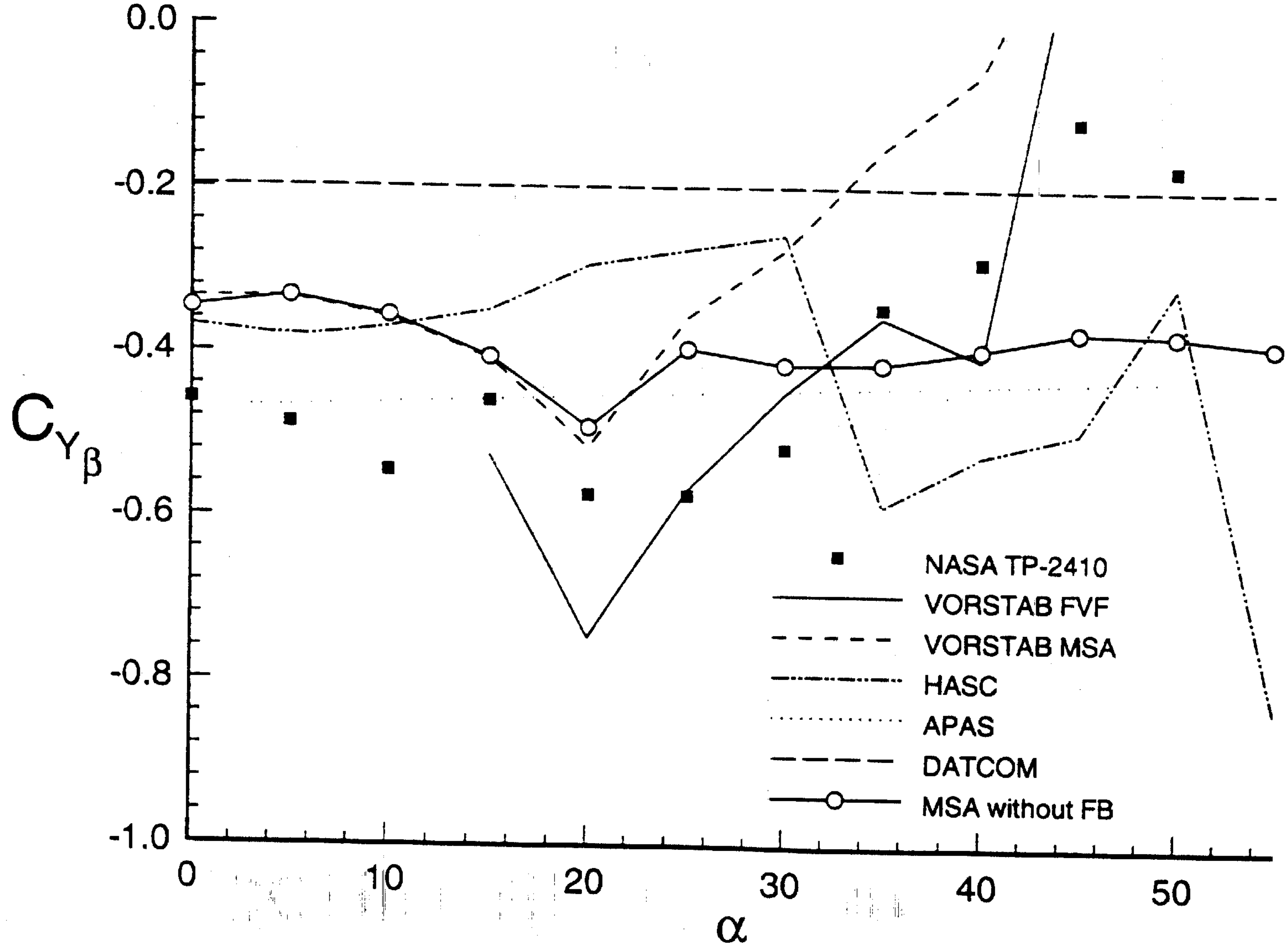
COMPARISON OF RESULTS

Summary of Longitudinal Results F16XL

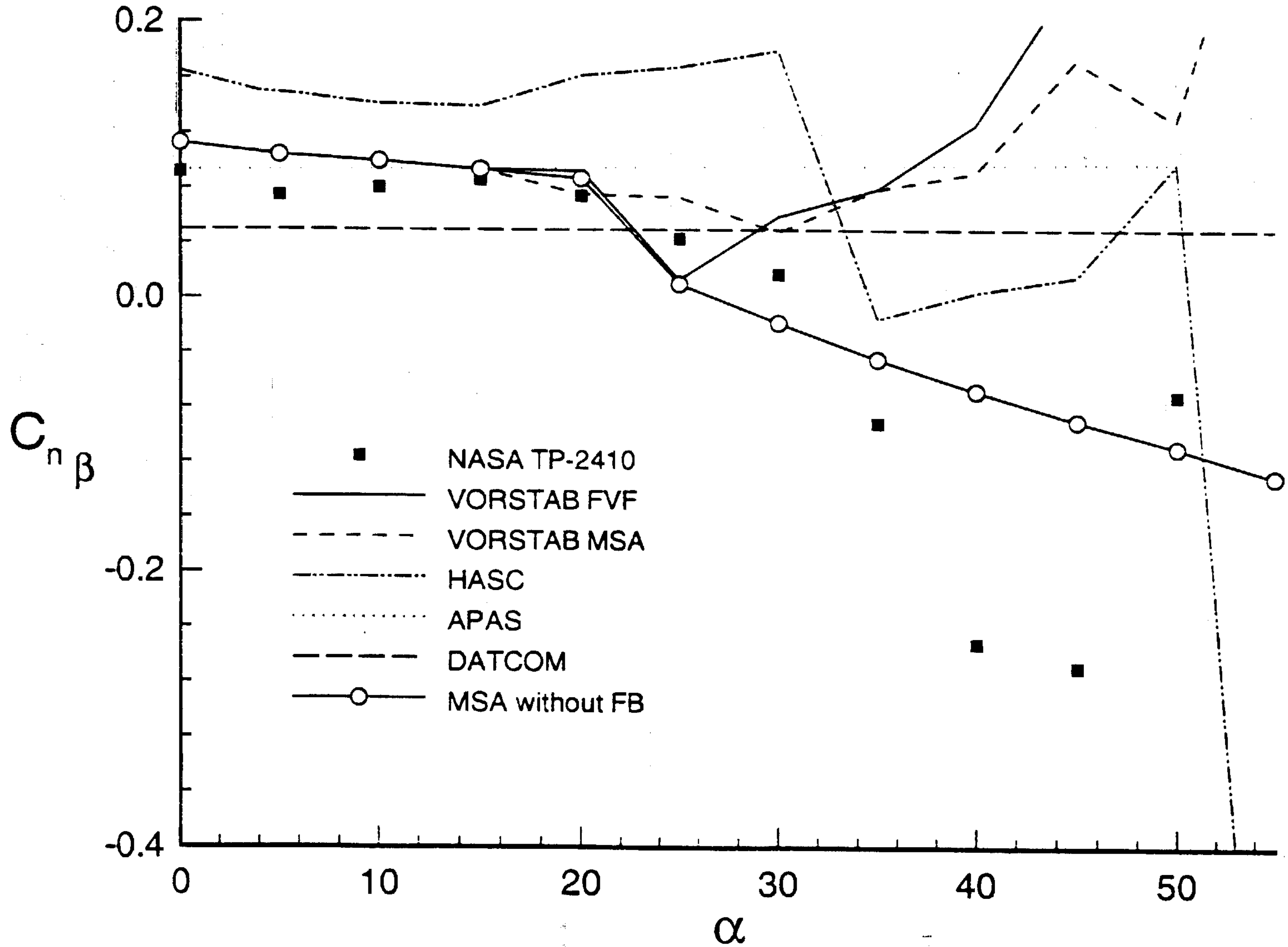
	C_L mod. α	$C_{L_{max}}$	$\alpha_{C_{L_{max}}}$	C_{M_o}	C_M vs α	C_D vs C_L	ΔC_M MAG	ΔC_M TRENDS
DATCOM	√	X	NA	—	X	√ mod. C_L	√	—
VORSTAB MSA	—	√	—	√	X / — no AVL	√	X	√
VORSTAB FVF	X	—	√	NA	X	—		
HASC	—	√	—	—	X	X		
APAS	—	X	NA	√	X	—	X	X

√ = GOOD — = FAIR X = POOR

COMPARISON OF RESULTS
F-16XL



COMPARISON OF RESULTS F-16XL



COMPARISON OF RESULTS
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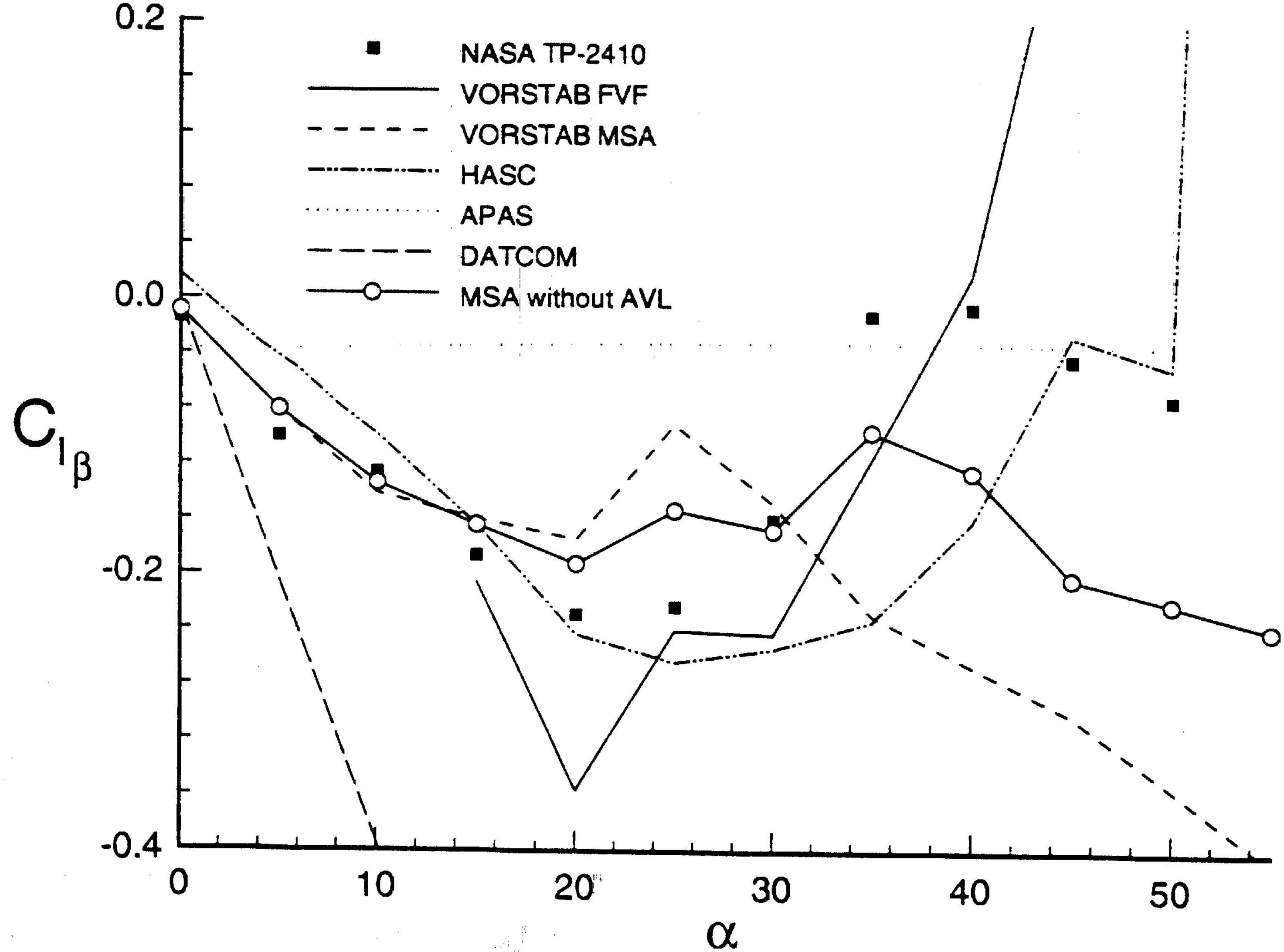

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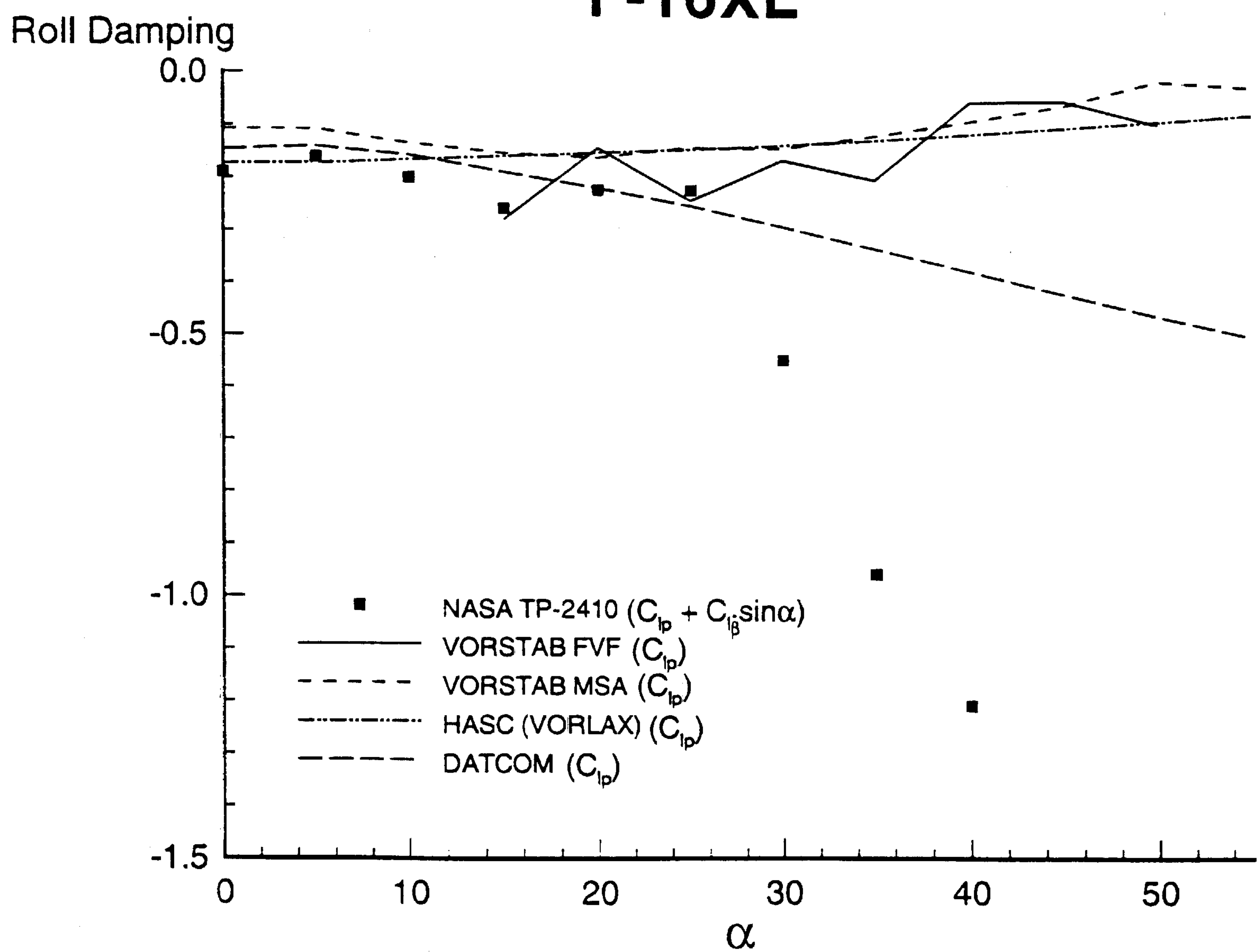
F-16XL



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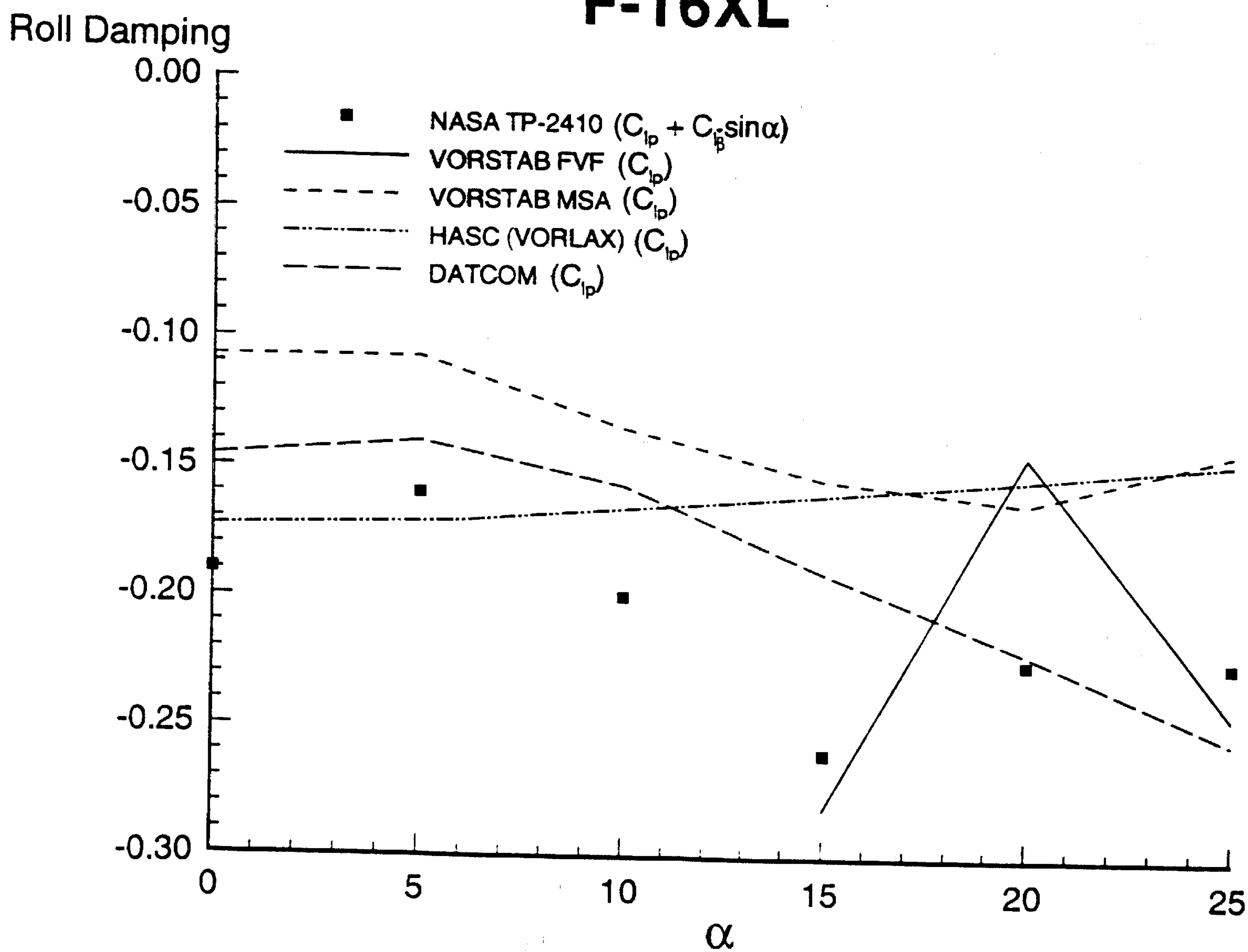

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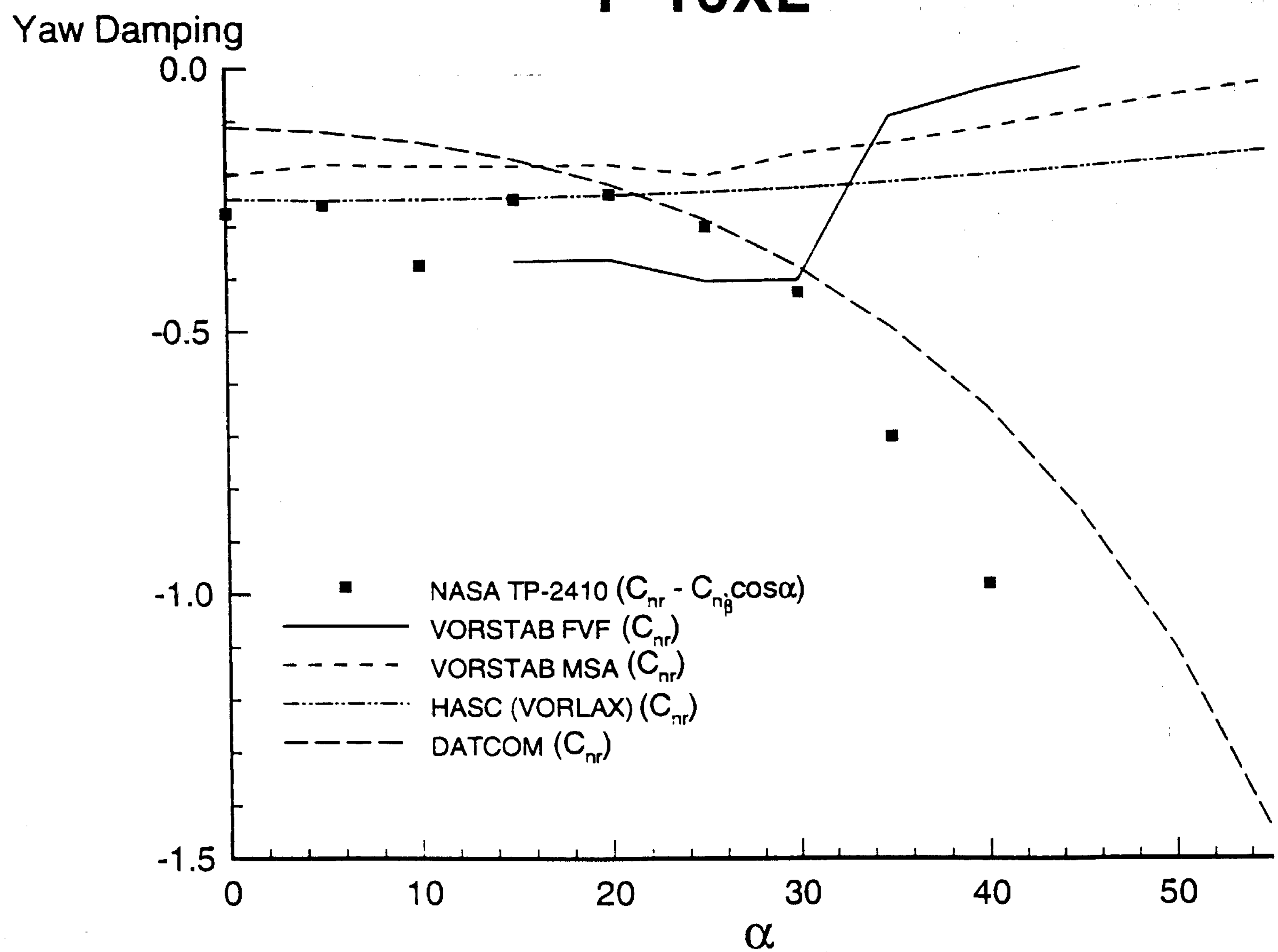
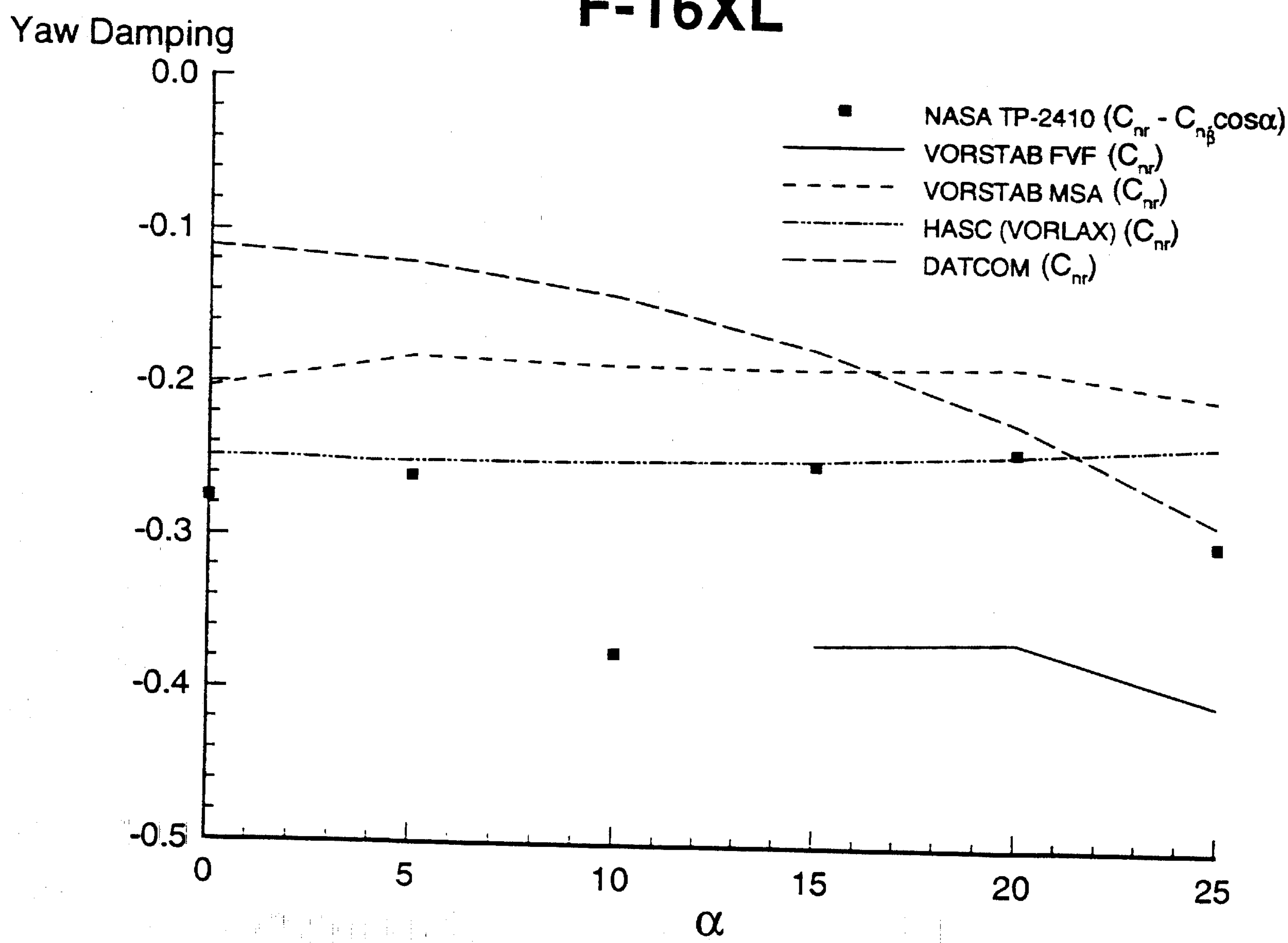
F-16XL



COMPARISON OF RESULTS
F-16XL



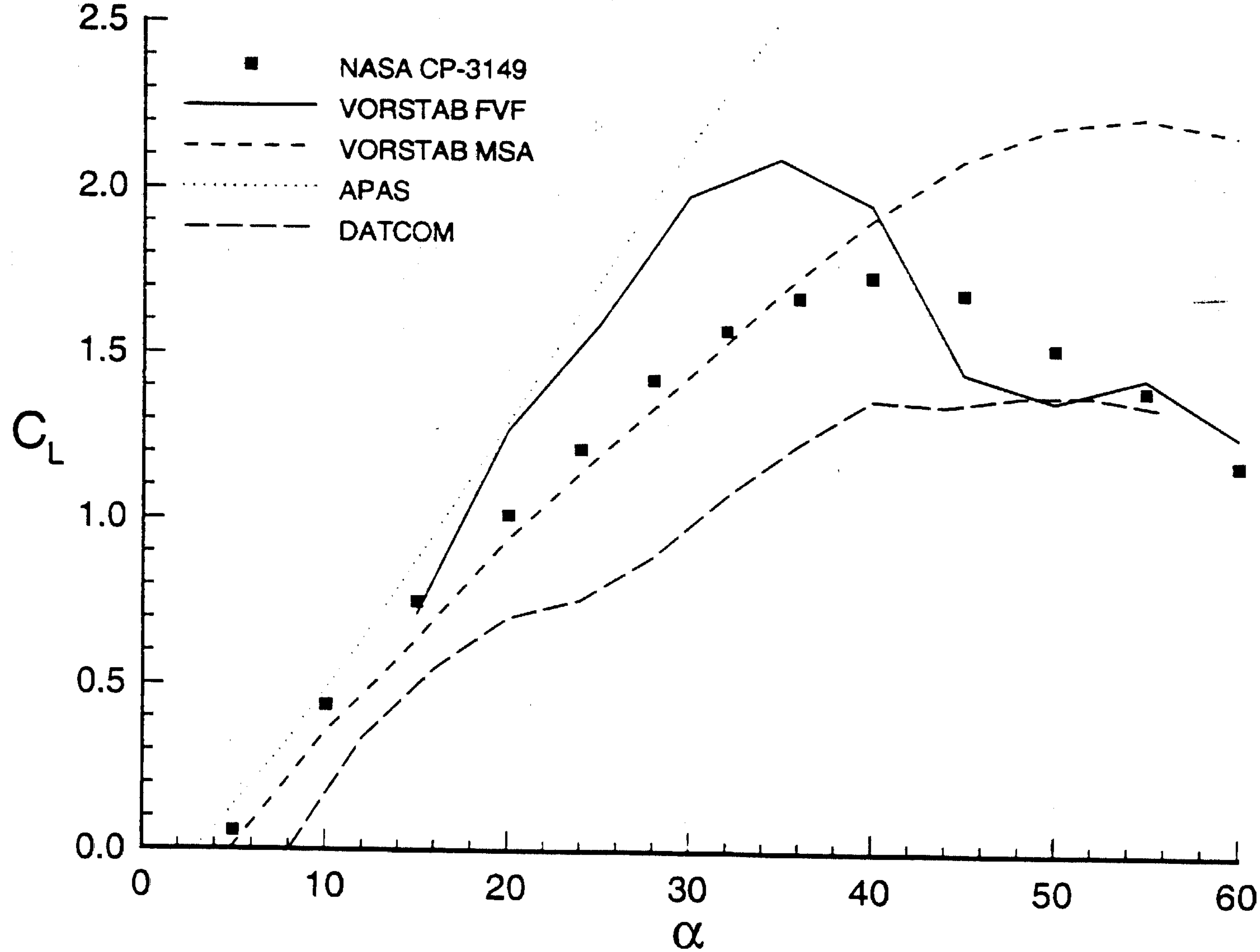
COMPARISON OF RESULTS

Summary of Lateral/Directional Results F16XL

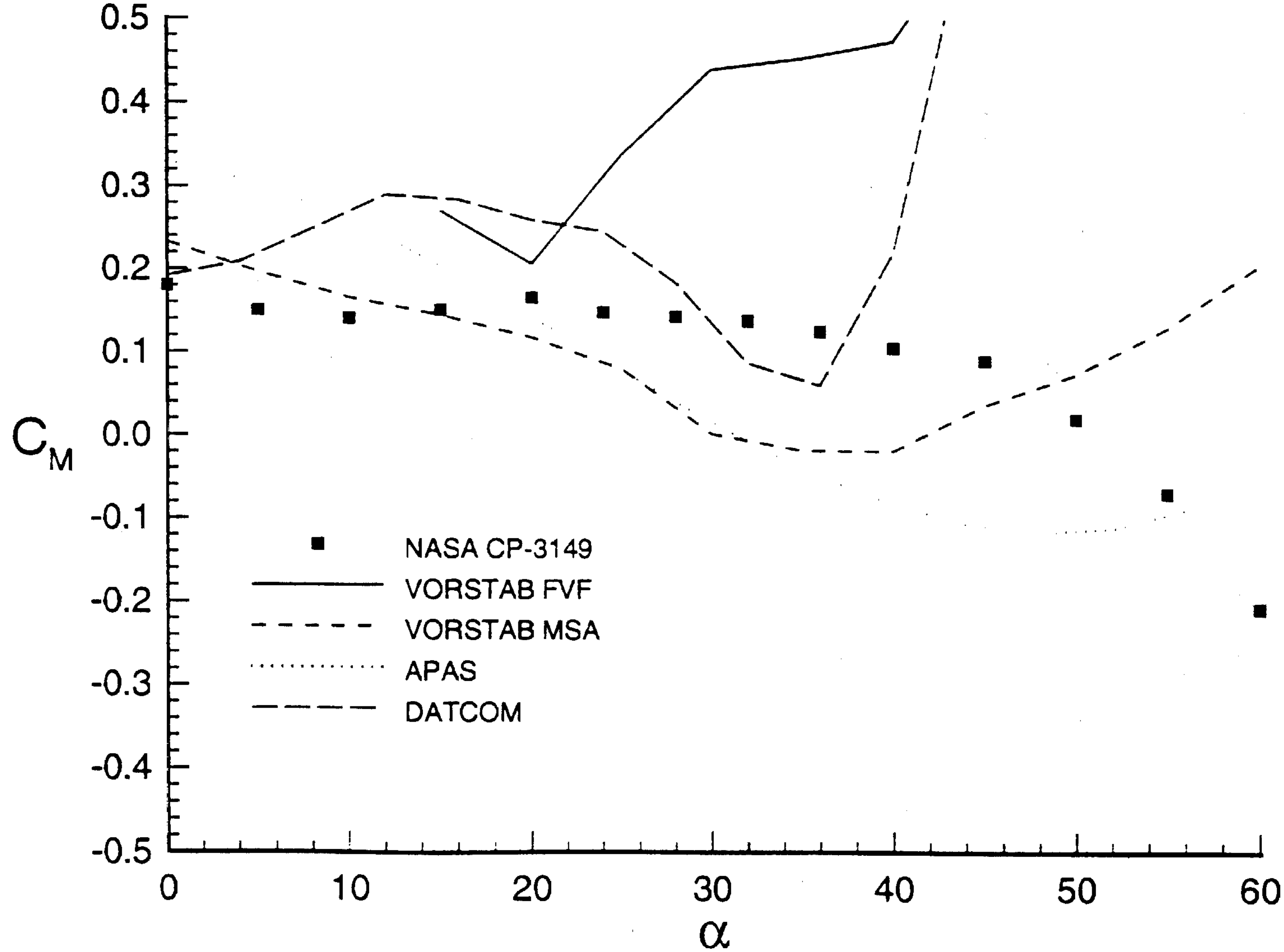
	C_{Y_β}		C_{n_β}		C_{l_β}		C_{l_p}	C_{n_r}
	$\alpha=0$	vs. α	$\alpha=0$	vs. α	$\alpha=0$	vs. α	Low α	Low α
DATCOM	X	X	—	X	√	X	√	X
VORSTAB MSA	—	√	√	√ $\alpha<30$ X $\alpha>30$	√	√ $\alpha<20$ X $\alpha>20$	X	—
VORSTAB FVF	√ ($\alpha=15$)	√	√ ($\alpha=15$)	√ $\alpha<30$ X $\alpha>30$	√ ($\alpha=15$)	√ $\alpha<35$ X $\alpha>35$	√	X
HASC	—	X	X	— $\alpha<35$ X $\alpha>35$	√	√ $\alpha<25$ — $\alpha>25$	—	√
APAS	√	X	√	X	√	X		

√ = GOOD　　— = FAIR　　X = POOR

COMPARISON OF RESULTS
F-18



COMPARISON OF RESULTS
F-18



COMPARISON OF RESULTS

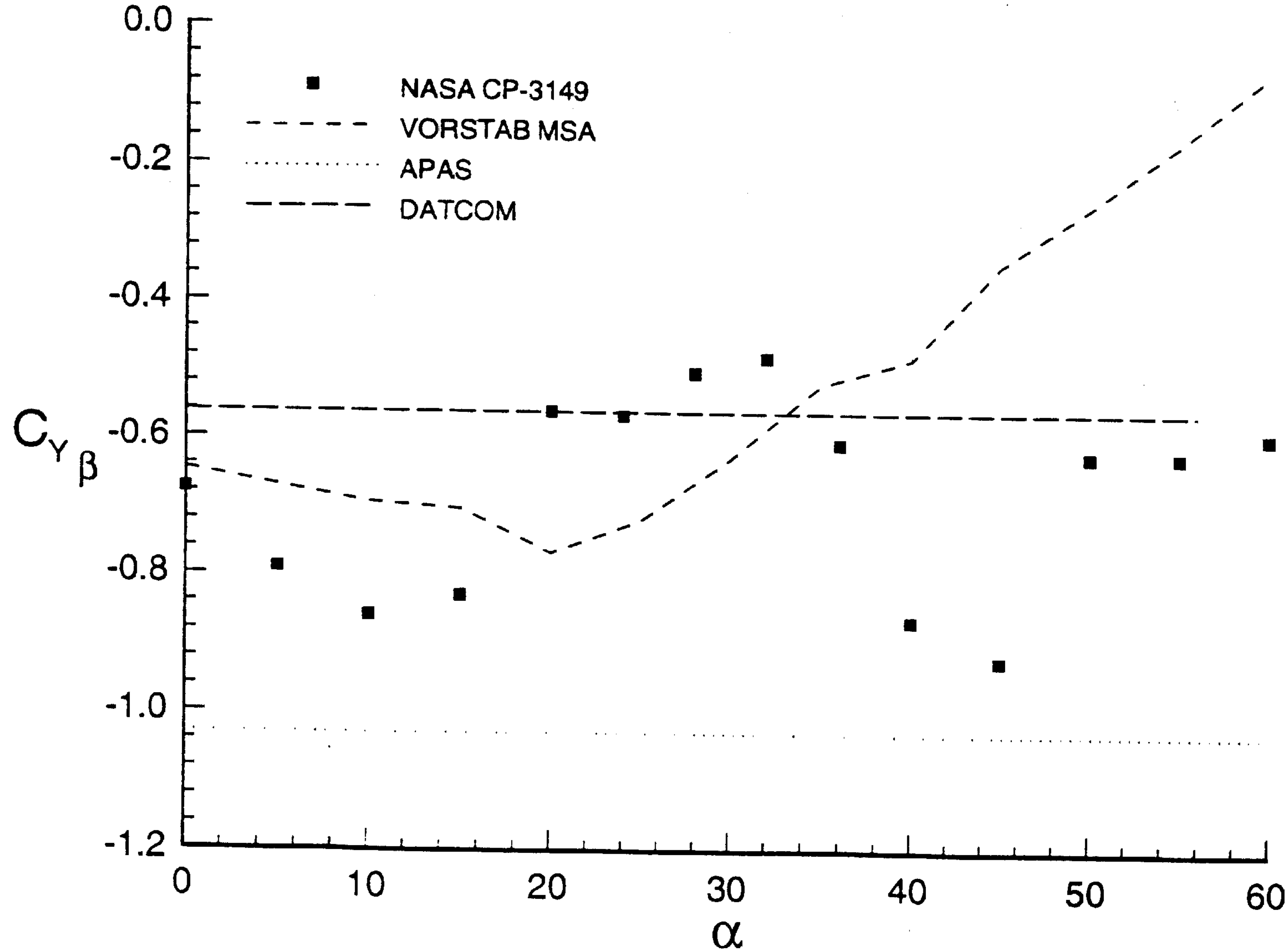
Summary of Longitudinal Results F18

	C_L mod. α	$C_{L_{max}}$	$\alpha_{C_{L_{max}}}$	C_{M_o}	C_M vs α	C_D vs C_L	ΔC_M MAG	ΔC_M TRENDS
DATCOM	X	X	—	√	— (α < 35)			
VORSTAB MSA	√	X	—	√	—			
VORSTAB FVF	X	—	—	NA	X			
HASC								
APAS	X	X	NA	—	—			

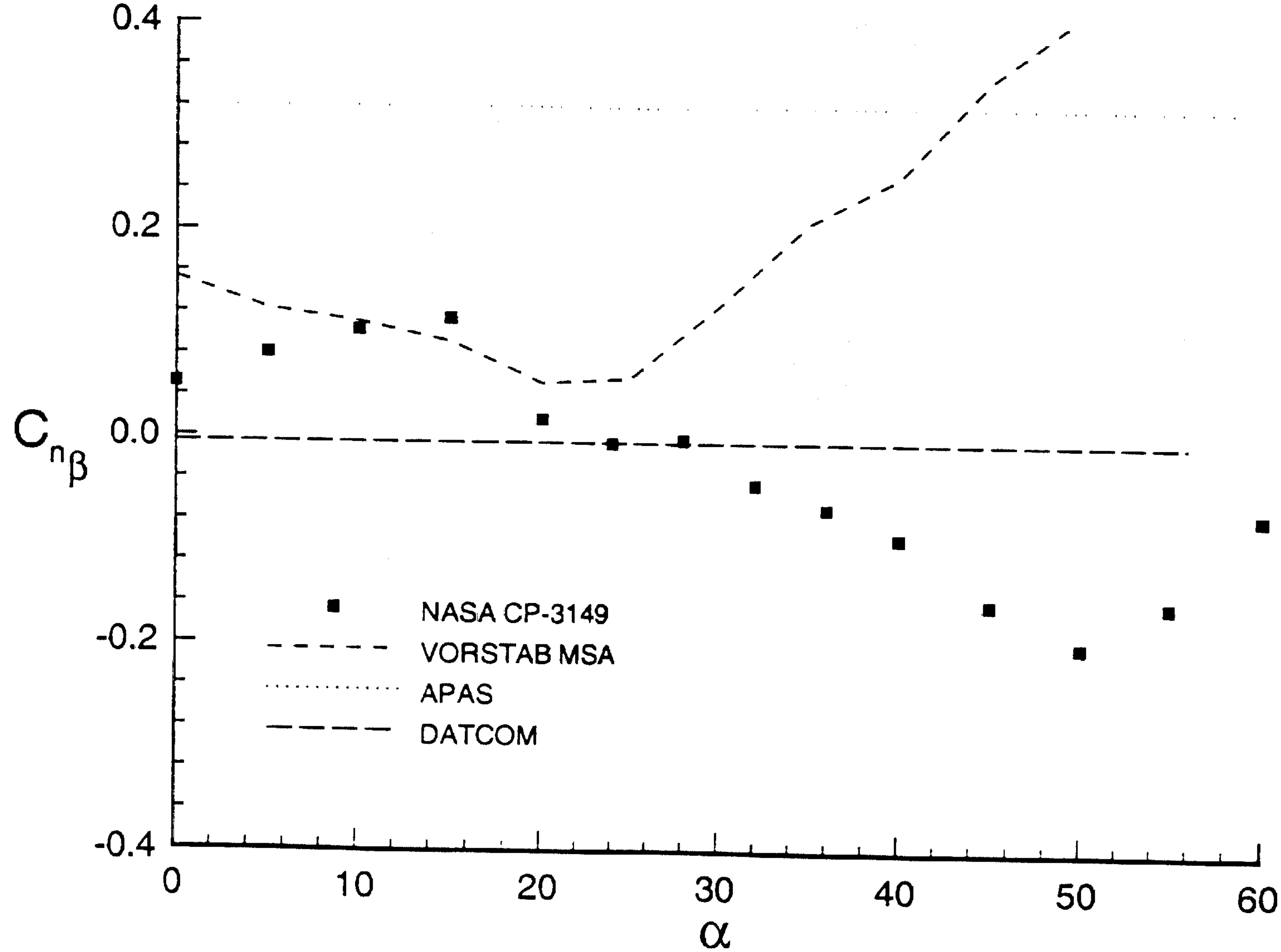
√ = GOOD — = FAIR X = POOR

◯ = same as F16XL comparison

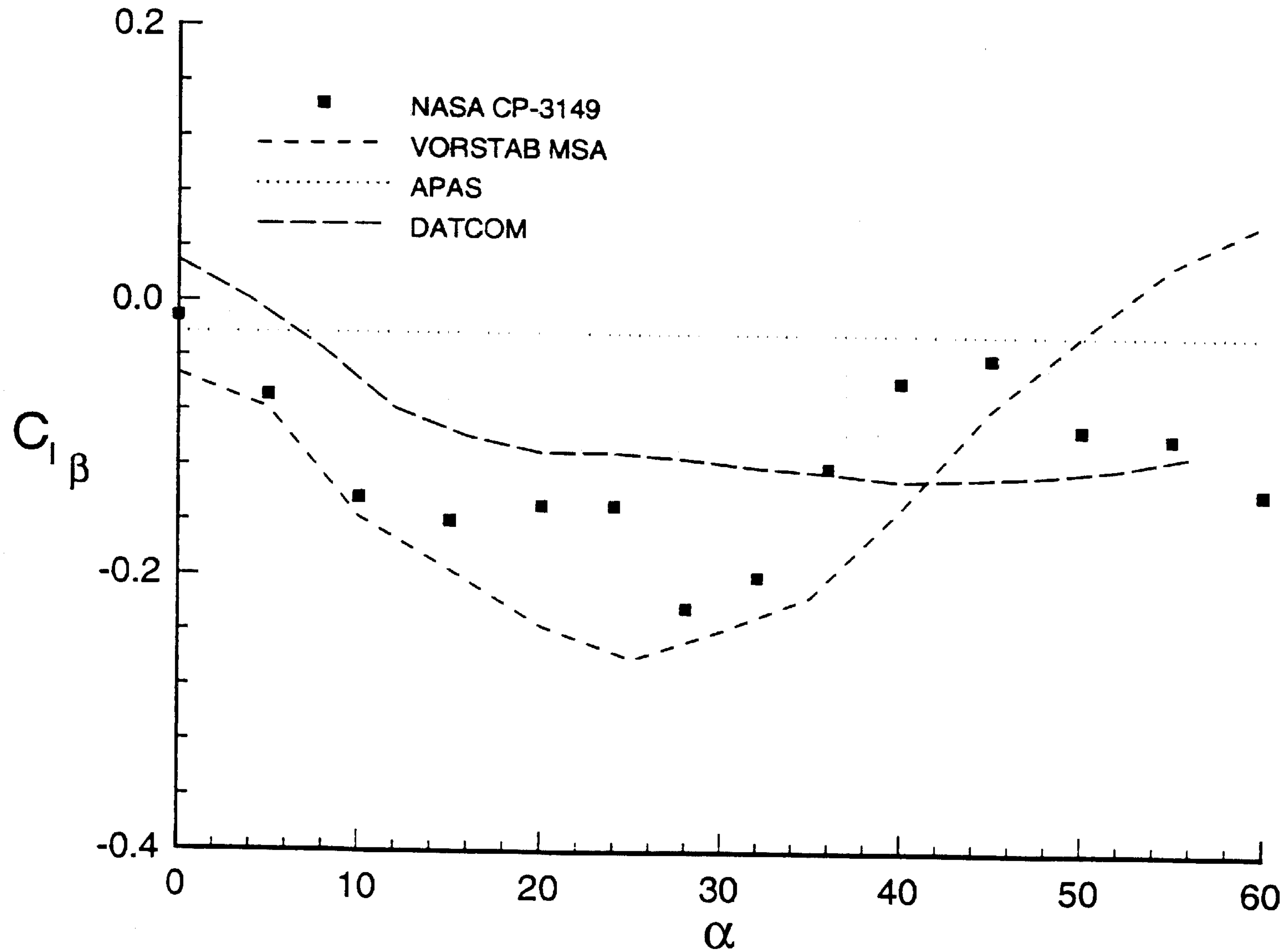
COMPARISON OF RESULTS
F-18



COMPARISON OF RESULTS
F-18



COMPARISON OF RESULTS
F-18



COMPARISON OF RESULTS

Summary of Lateral/Directional Results F18

	C_{Y_β}		C_{n_β}		C_{l_β}		C_{l_p}	C_{n_r}
	$\alpha=0$	vs. α	$\alpha=0$	vs. α	$\alpha=0$	vs. α	Low α	Low α
DATCOM	√	X	—	X	—	—		
VORSTAB MSA	√	√ $\alpha<30$ X $\alpha>30$	—	— $\alpha<30$ X $\boxed{\alpha>30}$	√	√ $\alpha<40$ X $\alpha>40$		
VORSTAB FVF								
HASC								
APAS	X	X	X	X	√	X		

√ = GOOD — = FAIR X = POOR

◯ = same as F16XL comparison

HIGH-ANGLE-OF-ATTACK AERO PREDICTIONS

General Comments

- Existing Codes not User Friendly
- Can Be Sensitive and Unstable w.r.t. Geometry
- Unconventional Layouts Difficult to Model
- Can Be Sensitive to "Extra" Input

HIGH-ANGLE-OF-ATTACK AERO PREDICTIONS

Conclusions

- No One Code Predicts All Important Parameters
- Codes Do Not Give Consistent Results
- More Sophisticated Methods Do Not Always Give Better Results

HIGH-ANGLE-OF-ATTACK AERO PREDICTIONS

Recommendations

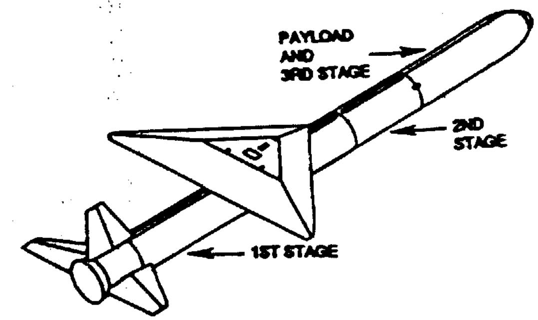
- Capable of Handling Complex Configurations
- Graphical Interface w/ 3D Geometry Input
- Ouput of Force and Moment Coefficients
- Minimal Input in Addition to Geometry, Flow Conditions, and Program Control

LESSONS LEARNED IN THE COMPUTATIONAL AERODYNAMIC DESIGN OF PEGASUS®

Michael R. Mendenhall
Nielsen Engineering & Research

Nonlinear Aerodynamic Prediction Requirements Workshop
NASA Langley Research Center
December 8, 1993

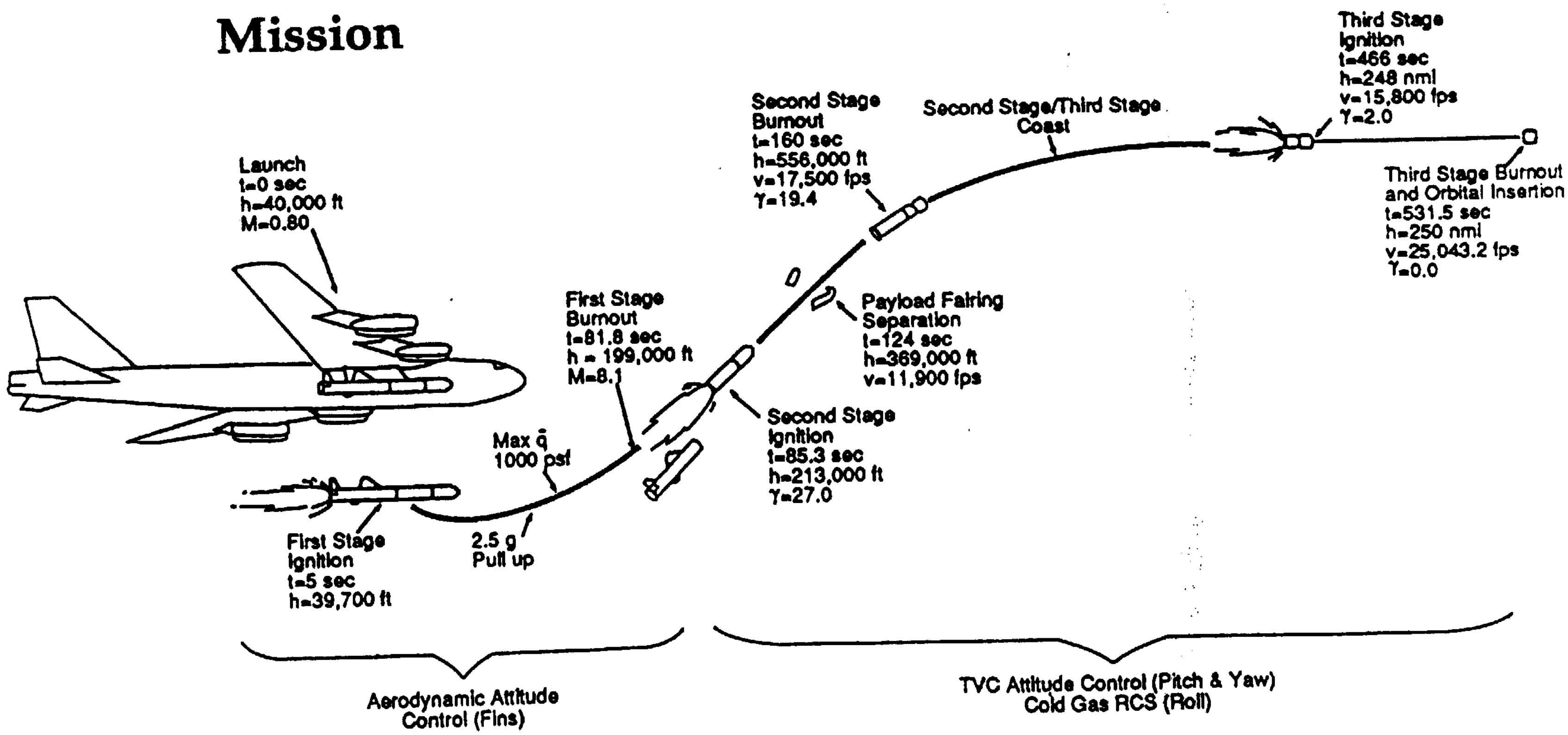
INTRODUCTION



Pegasus

- B-52 Launched
- First-Stage Aerodynamics

Mission



AERODYNAMIC DESIGN REQUIREMENTS

Outline

- Schedule
- Cost
- Procedure
- Flight Conditions
- Aerodynamics

REQUIREMENTS - SCHEDULE/COST

Concept to Flight in 2.5 Years

- Formal Aero Analysis Began September 1987
- First Pegasus Flight April 1990

Commercial Development

- Orbital Sciences Corporation
- Hercules Aerospace Company

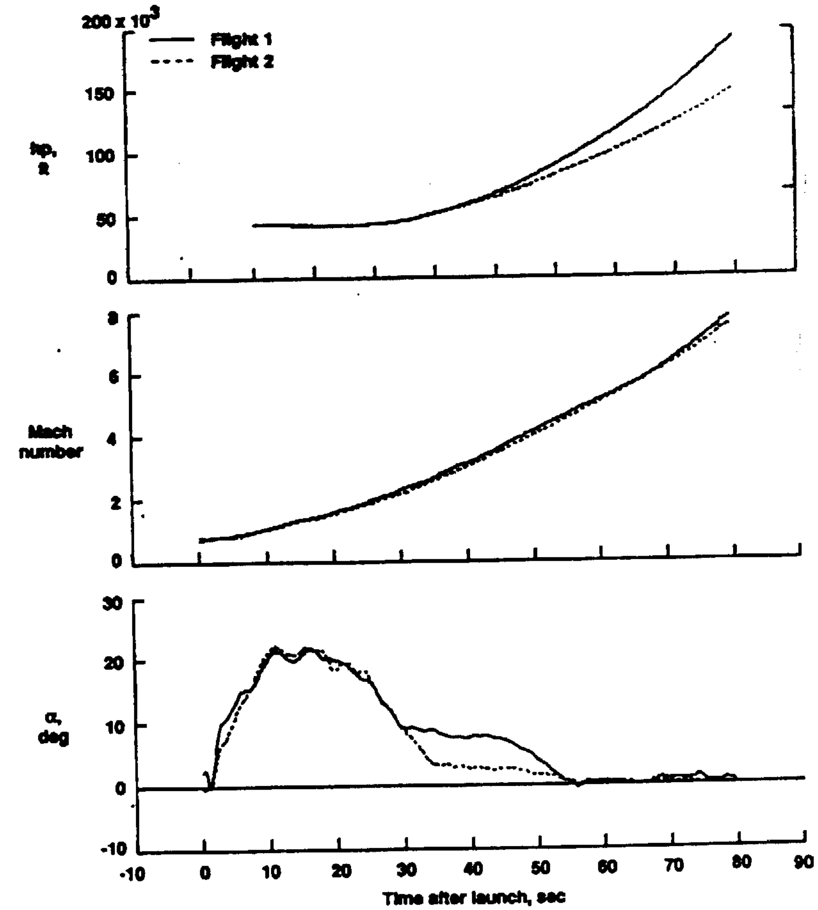
REQUIREMENTS - PROCEDURE

Aerodynamic Design and Analysis

- Using Computational Methods
- No Wind Tunnel Tests
- No Flight Tests

REQUIREMENTS - FLIGHT CONDITIONS

- $M_\infty = 0.8$ to 8.0
- $\alpha = -5$ to $25°$
- $h = 40{,}000$ to $200{,}000$ ft.



REQUIREMENTS - AERODYNAMICS

Performance Analysis

Mission Simulation Aerodynamic Matrix

- $\simeq$ 1500 Flow Conditions

Stability and Control

Structural Design and Analysis

B-52 Carriage Loads

Launch Characteristics

- Nominal
- Emergency

ANALYSIS PROCEDURES/TECHNIQUES

Multiple Independent Prediction Methods

Validated Models

Minimum Method Development

Frequent Sanity Checks
- Wind Tunnel Data for Similar Configurations
- X-15 Flight Data

ANALYSIS - PREDICTION METHODS

Empirical/Database Methods

Potential Models with Viscous Effects

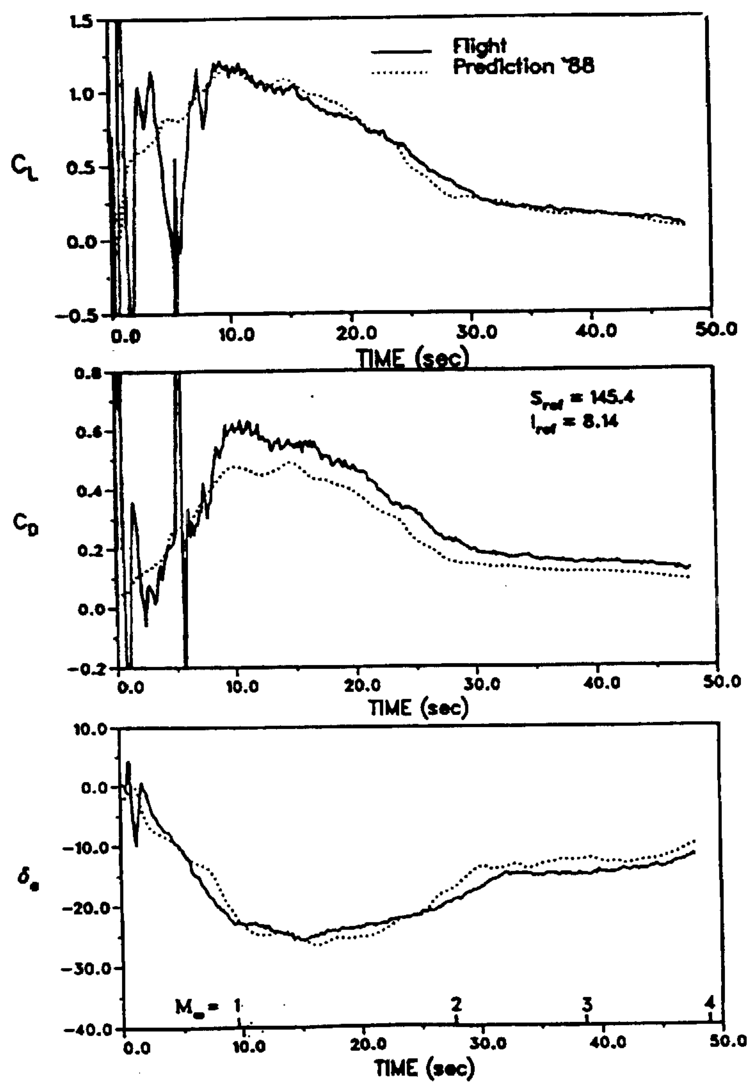
Engineering/Semi-Empirical Methods

Euler Methods

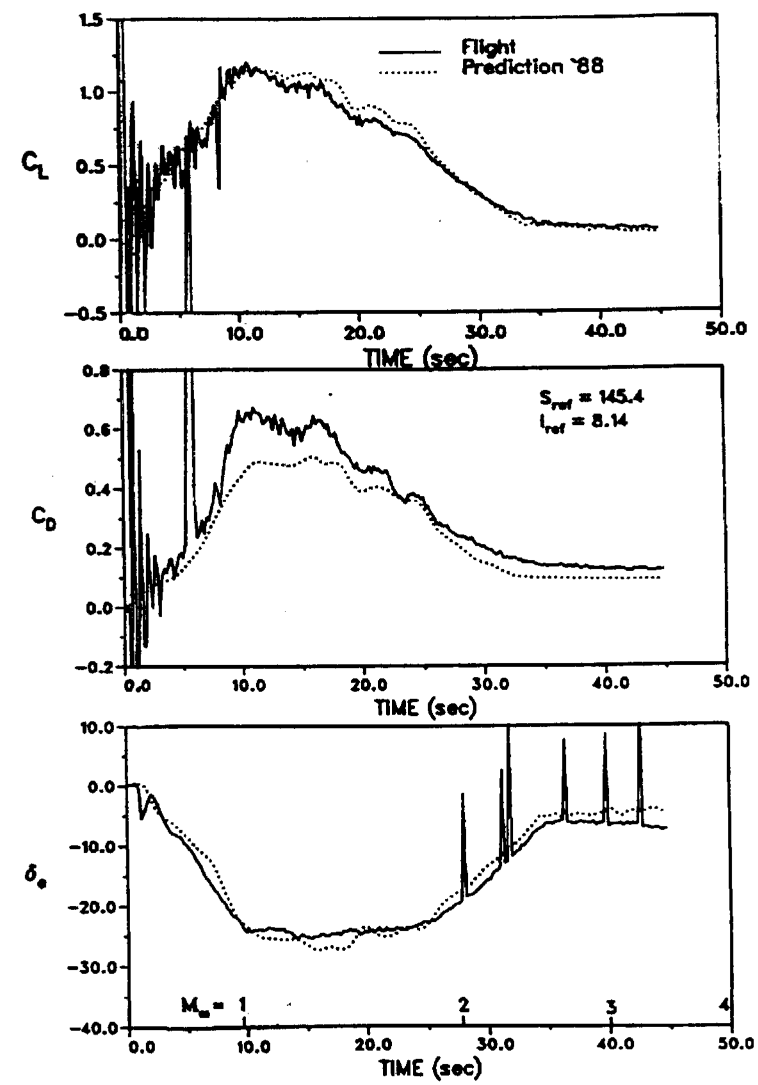
Parabolized Navier-Stokes Methods

Reynolds Averaged Navier-Stokes Methods

RESULTS - AERODYNAMICS



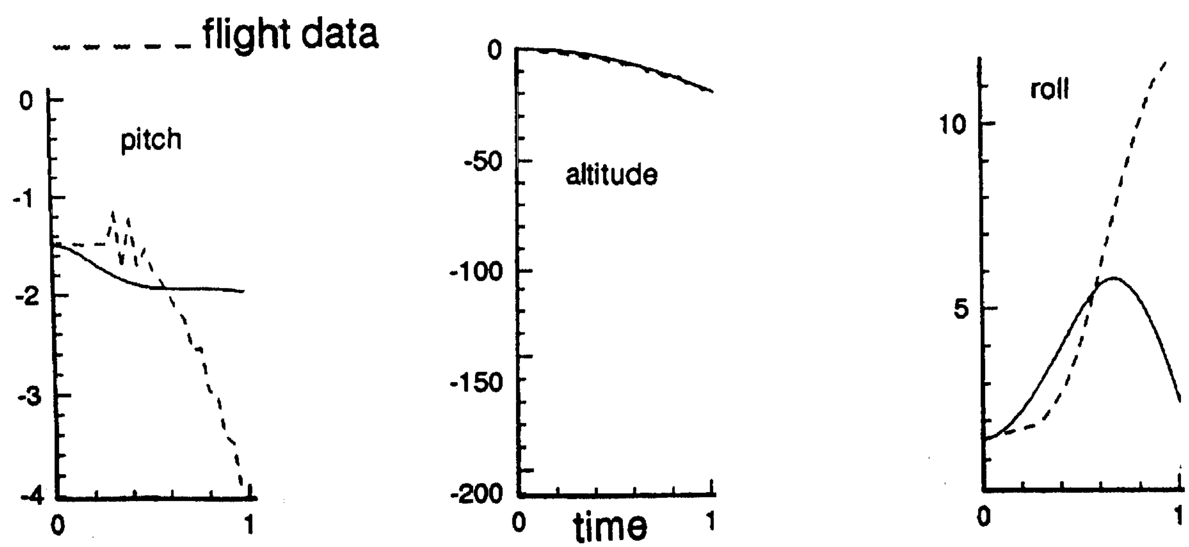
PEGASUS – FLIGHT 1



PEGASUS – FLIGHT 2

RESULTS - CARRIAGE AND LAUNCH

Flight 1



LESSONS LEARNED

Computational "Tool Box" is Necessary

- Overlapping Independent Methods
- All Levels of Available Technology

Specific Emphasis Required in Certain Areas

- High Angles of Attack (Separation, Vorticity, ...)
- Transonic Speeds (Nonlinear Effects, Drag, ...)
- Loading Distributions (Center of Pressure)
- Carriage Loads (Close Coupled Two-Body Problem)
- Launch Characteristics (Interference Effects Necessary)
- Trajectory Simulation (Clearance Evaluation)

RECOMMENDATIONS

Engineering Methods for Preliminary Design

- Continue Development
- Continue Validation
- Improve Economy, Accuracy
- Integrate New Technology

Computational Fluid Dynamics (CFD)

- Continue Development and Validation
- Improve Algorithms, Grid Generation
- Develop Appropriate Turbulence Models
- Improve Economy, Accuracy, Computer Requirements

CONCLUSIONS

Don't forsake useful technology simply because a higher level is available or fashionable.

All levels of technology are required for the aerodynamicist's tool box, and as technology develops and matures, the higher level methods are more commonly used.

Yesterday's CFD is today's Engineering Method.

ACKNOWLEDGEMENTS

Orbital Sciences Corporation

- For sponsorship of the Pegasus analysis
- For accepting the computational results

NASA (Ames and Langley Research Centers)

- For access to the latest CFD codes
- For computer resources

REFERENCES

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NON-LINEAR AERO PREDICTION REQUIREMENTS WORKSHOP

8-9 December 1993

KM Dorsett
SE Peters
Aerodynamic Stability & Control

- **Data Needs & Rationale**
- **Priorities for Data**
- **Accuracy Requirements**
- **Approaches Available**
- **Database Availability**
- **Validation of Methods**
- **Recommendations**

WHY IS IMPROVED PREDICTION CAPABILITY NEEDED FOR NON-LINEAR AERODYNAMICS?

- **Current Tools Do Not Fulfill Needs**
  - Unrepresentative for Non-Linear Conditions (Elevated AOA, Controls Effects, etc.)
  - Cumbersome & Inefficient Handling, Non-Portable, Unreliable
  - Stability & Control Requirements Are Not Met

- **Changing Mission Requirements Increase Emphasis on Non-Linear Conditions**
  - More Complex Controllers
  - High AOA Capability with High Agility

- **Accurate Non-Linear Characteristics Required to Improve Preliminary Design**
  - Stability & Control (AOA Capability, Maneuver Capability)
  - Takeoff & Landing (Trimmed Lift & Drag through Stall, Dynamic Characteristics)
  - Air-to-Air Combat (Maneuver Capability, Agility)

- **Opportunities Exist for Improved Design Tools**
  - More Capable Computers
  - Development of Aero Prediction Methodologies
  - More Empirical Data are Available for Modern Tactical Aircraft than Incorporated in Existing Tools.

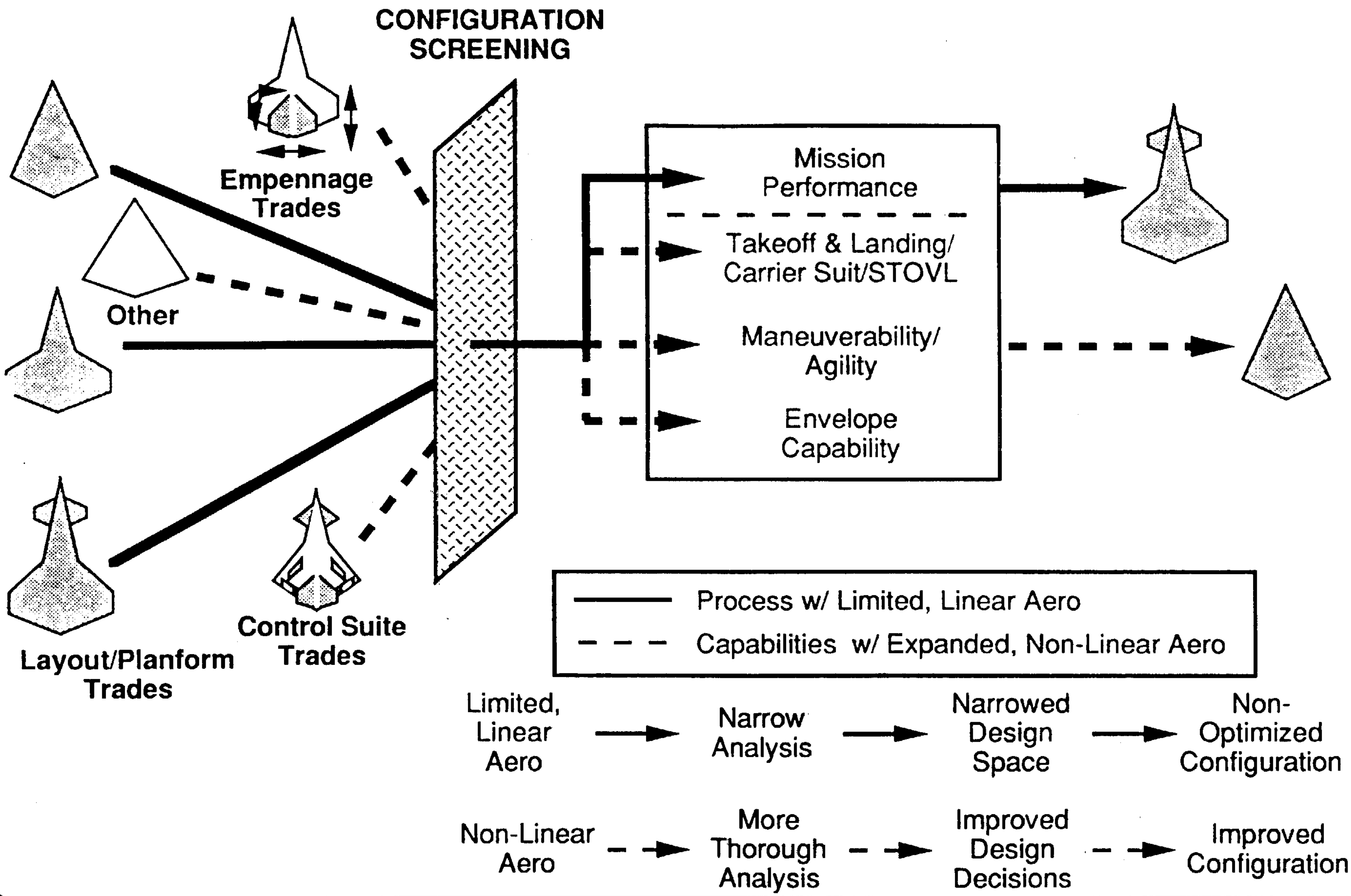
- **Increasing Customer Expectations**
  - A/C Capability
  - Design Capability

These Factors Create the Requirement and Opportunity for Improved Non-Linear Aero Predictions in Preliminary Design.

IMPROVEMENT OF NON-LINEAR AERO PREDICTIONS IN PRELIMINARY DESIGN PROVIDES MAJOR PAYOFFS

Analysis	Mission Performance	Takeoff & Ldg/ Carrier Suit/STOVL	Maneuverability/ Agility	Envelope Capability
Predicted Quantities	Range/ Payload	• Stall Margin • Roll Performance • Flying Qualities • Vrot/Vnwlo • Climb • Engine Out • Power Induced Effects • Ground Effects	• Turn Rate • Roll Performance • Pitch Agility • Excess Power	• Vmax • Vmin • Max AOA
Aero Parameter Req'mts C_L C_D C_m C_l C_n C_Y	Cruise/Dash Low α Low Control Deflections	Low Speed Moderate α Partial Flow Sep. Large Deflections Sideslip Power Effects Interference	Low Speed to Supersonic Low α to High α Attached to Fully Separated Large Control Deflections Sideslip Dynamic Unsteady Power Interference	

PRELIMINARY DESIGN APPLICATIONS FOR NON-LINEAR TOOLS



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DATA REQUIREMENTS VARY WITH CONFIGURATION AND MISSION

- Methods Development Should Be Prioritized To Focus On Design Needs And Opportunities.
- Needs & Priorities During The Preliminary Design Vary With Configuration And Mission Requirements

Agility / Signature	Low - Med Maneuverability Class II	High Maneuverability @ Low - Moderate α Class IV	High Maneuverability @ Low - High α
No Signature Considerations	C_L, C_D, C_m	Increased Data Requirements in Preliminary Design	
Low Observables			• C_L, C_D, C_m • Lat-Dir Stab • Control Effect • Dynamic Effects

- 3rd Dimension of Table is Terminal Flight Performance & Control (STOVL, Carrier Suitability)

Design Tools Should Aim for the Challenging Case of LO Configurations with High Maneuverability & High AOA Capability

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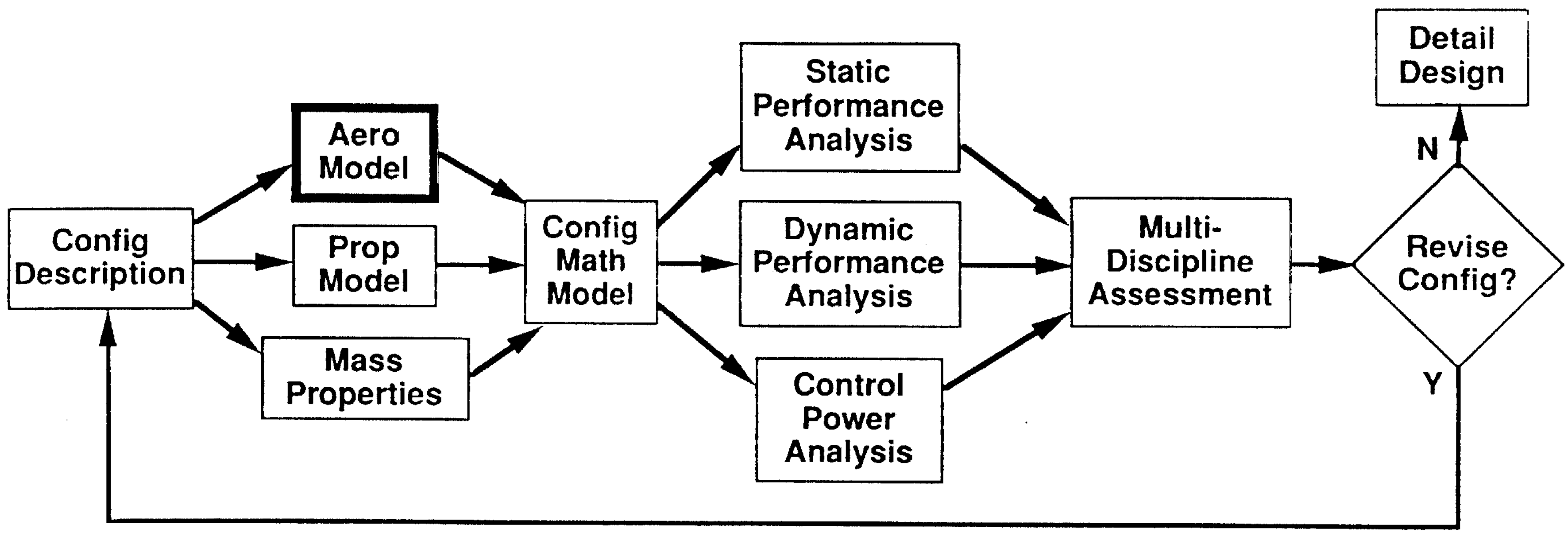
TOOL DEVELOPMENT SHOULD PROCEED IN ORDER OF PRIORITY, BASED ON DESIGN NEEDS

Priority	Data Requirement
Avail	Longitudinal Aero at Low AOA
1	Longitudinal Aero Through and Beyond Stall
1	Lat/Dir Stability Through and Beyond Stall
1	Control Power Through and Beyond Stall
2	Forebody Vortex Control Effectiveness
2	Control Interaction Effects
3	Effect of β on Controls
3	Effect of β in Longitudinal Data
3	Dynamic Derivatives
3	Power Induced Effects
4	Rotational Effects
4	Unsteady/Dynamic Effects
4	External Store Effects
4	Bay Effects

- **Meeting Priority 1 and 2 Requirements Would Represent a Significant Step Forward**
- **Meeting Other Priority Needs Would Further Improve Preliminary Design Products**

EFFORTS SHOULD NOT BE DILUTED WITH CONTROL SURFACE SIZING

- Design Process Needs to be Modular to Take Advantage of Advances in Various Areas



- Tools Exist & are Regularly Improved for Each Module
- Focus on Improving Predictions for Aerodynamic Characteristics
- Integrate Input & Output with Design Tools (e.g., CAD Formats, CSEF)

ACCURACY REQUIREMENTS FOR AERO PREDICTIONS

- **ACCURACY NEEDS DEPEND ON CONFIGURATION SENSITIVITIES**
  - Sensitivities Vary with Configuration, Mission, AOA, and Mach
  - More Critical for:
    - Neutral or Unstable Configurations
    - Configurations with Non-Linear or Multi-Axis Controllers
    - Highly Maneuverable Aircraft

- **ACCURACY NEEDS VARY WITH DESIGN MATURITY**
  Early Design Requires Trends, Later Design Requires Absolute Values

- **SENSITIVITIES (& ACCURACY REQMNTS) ARE DETERMINED AFTER PRELIMINARY DATA ARE AVAILABLE**

- **ACCURACY GUIDELINES HAVE BEEN COMPILED BASED ON EXPERIENCE WITH CURRENT TACTICAL AIRCRAFT & DESIGNS**
  - Caution Should Be Exercised With Accuracy Guidelines
  - At Elevated AOA or High Speed, Accuracy Requirements May Be More Stringent, Dependent on Configuration, Maneuverability,...
  - Express Values in Dimensional Terms for Unconventional Configurations
  - Sensitivity Analyses Must Be Done to Update Accuracy Requirements

Basic Data		Control Power		Damping Ders	
$C_{m\alpha}$, $C_{N\alpha}$	5-15%	$C_{m\delta}$	5-15%	C_{mq}	10-30%
$C_{l\beta}$, $C_{n\beta}$	5-15%	$C_{l\delta}$	5-15%	C_{lp}	5-15%
C_D	5-20%	$C_{n\delta}$	5-20%	C_{nr}	5-30%

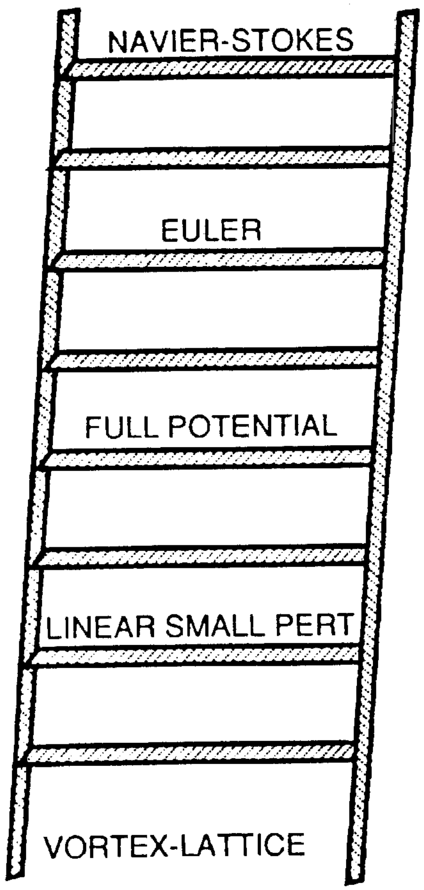
TWO METHODS ARE AVAILABLE TO IMPROVE ACCURACY OF AERO PREDICTIONS

- THEORETICAL AERO
  - Improvements in Non-Linear Aero CFD Predictions Will Require High Order Codes
  - Current High Order Codes & Computers Do Not Support Preliminary Design Requirements
  - Advances in Computers, Theoretical Aero, & Codes Hold Significant Potential in the 'Near' Future
  - Developers of High Order Codes Require Guidance from Preliminary Design Community

- SEMI-EMPIRICAL
  - Low Order Codes Can Be Made More Useful By Incorporating Corrections Based on Existing Empirical Data
  - Significant Opportunities & Obstacles Exist
  - Much Empirical Data Exists Which is Not Included in Low Order Codes
  - Most Data, or Most Interesting Data, Has Security or Company Proprietary Restrictions

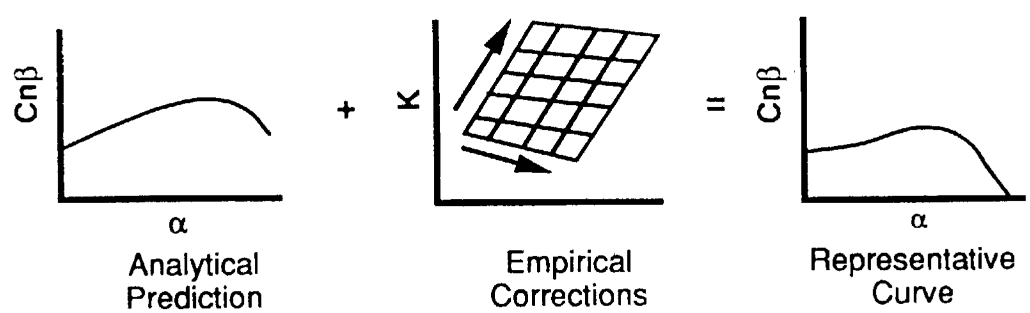
- THE TWO METHODS ARE NOT MUTUALLY EXCLUSIVE

SEMI-EMPIRICAL APPROACH IS PROBABLY THE MOST PRODUCTIVE NEAR-TERM SOLUTION



THEORETICAL AERODYNAMICS

- CLIMBING THE CFD LADDER MAY REQUIRE GOING TO THE TOP
  - Other Improvements May Also Be Needed (Turbulence, ...)
  - Computers in Prelim Design Needed to Support CFD in Future
- EMPIRICAL CORRECTIONS TO THEORETICAL EQUATIONS WILL BE REQUIRED TO RELIABLY PREDICT:
  - Vortex Stability, Breakdown, Interactions, etc.
  - Vortex Interaction With Empennage And Control Surfaces
  - Control Interference Effects
  - Weapons Bay/Store Effects
  - Linear, Attached Flow Predictions
- COMPUTERS, THEORY, AND CODE MAY MATURE SUFFICIENTLY TO REPLACE SEMI-EMPIRICAL METHODS IN 5 TO 10 YEARS



SEMI-EMPIRICAL METHODS

ADVANCES IN NON-LINEAR PREDICTION CAPABILITIES CAN BE MADE BY IMPROVING INTERFACE

- **SOME CAPABILITIES OF EXISTING TOOLS ARE UNUSED DUE TO DIFFICULT USER INTERFACE**

- **DEVELOPMENT OF ANY NEW CODE SHOULD PAY CLOSE ATTENTION TO INTERFACE ISSUES**

- **INPUT / OUTPUT**
  - Echo Input, Including Geometry
  - Accuracy Dependent on Modeling Approach
  - Job Status, Interim Results in Case of Failure
  - Ability to Enter Existing Wind Tunnel Data
  - Compatibility with Other Design Tools (CAD, Graphics)
  - Graphical Flow Visualization (pressures, shocks, vortices, etc)
  - Intermediate Calculations

- **PORTABILITY OF CODE**
  - Machine
  - Language
  - Updates

- **DOCUMENTATION**
  - On-Line Help / Internal Documentation
  - Examples
  - User's Manual
  - User Feedback and Updates
  - Telephone Help Line

LFWC AERO DATA LIBRARY IS WELL SUITED FOR EMPIRICAL DATABASE DEVELOPMENT

- **Wide Range of Fighter, Attack, Trainer and Bomber Configuration Data**
  - Single Tail/Twin Tail/Tailless
  - Wing-Body/Flying Wing
  - Single Engine/Multi-Engine
  - Canard/3-Surface
  - STOVL
  - Vortex Control
  - Other (FSW, Oblique Wing, etc)

- **Wind Tunnel Data Types**
  - Static
  - Dynamic
  - Rotary
  - Pressure

Unclassified	Lockheed Proprietary	Classified
YF-16	Conventional Fighter	F-111 Derivatives
F-16	Tailless Concept	NATF
F-16 Agile Falcon	Wing Body	FX Proposal
SCAMP	Configuration	AFX/F-22
F-16XL	STOVL Concept	ASTOVL
F-16 AFTI		YF-22
F-111		Pre-Team ATF

Use Of Company Proprietary And Classified Data In A Public Empirical Database Requires Further Investigation

THE VALIDATION BENCHMARK SHOULD PUSH THE CURRENT STATE-OF-THE-ART

- **Suggested Requirements:**
  - **Longitudinal Aero** (Lift, Drag and Pitching Moment) beyond stall.
  - Predict **Longitudinal Control Power** (full nose-down) within 15% magnitude. Predict condition for Cm^*. Predict regions where breaks occur in pitching moment.
  - Predict **Lateral/Directional Stability** Derivatives to correct sign and within 15% magnitude. Show regions of instability
  - Predict **Roll Control Power** within 15% magnitude. Show regions of reversal.
  - Predict **Yaw Control Power** to within 20% Magnitude. Show regions of reversal.
  - Predict trends of all controls in sideslip.

- **Suggested Benchmark Configurations:**
  - Conventional Configuration with vortex dominated flows
  - Wing/Body
  - Tailless
  - Canard

GEOMETRIC CATEGORIZATION PARAMETERS

Wing/Airfoil
Aspect Ratio
t/c
Camber
Leading Edge Sweep (Multiple)
Trailing Edge Sweep (Multiple)
Dihedral/Anhedral (Compound)
L.E. Radius

Fuselage/Forebody
Forebody Bluntness
Forebody Shape
Nose Chine Area
Fineness Ratio
Nose Droop
Nose Volume
Aft-Body Shape
Canopy Shape

Propulsion System
Inlet Location
Inlet Shape
Nozzle Shape
Blown Surfaces
NPR

Strake/LEX
Area
Aspect Ratio
Sweep
Dihedral
Location

Weapons Carriage/ Bay Effects
Store Diameter
Location
Bay Size/Shape
Bay Depth
Fin Size/Location

Empennage/Canard
Sweep
Area
Aspect Ratio
Location (Chordwise/Spanwise)
Location with Respect to Vortices
Cant Angle

Blowing
Nozzle Shape
Nozzle Orientation
NPR
Blowing Coefficient

Control Surfaces
Hingeline Sweep
Shape/Size
Location with Respect to Other Surfaces/Vortices
Deflection

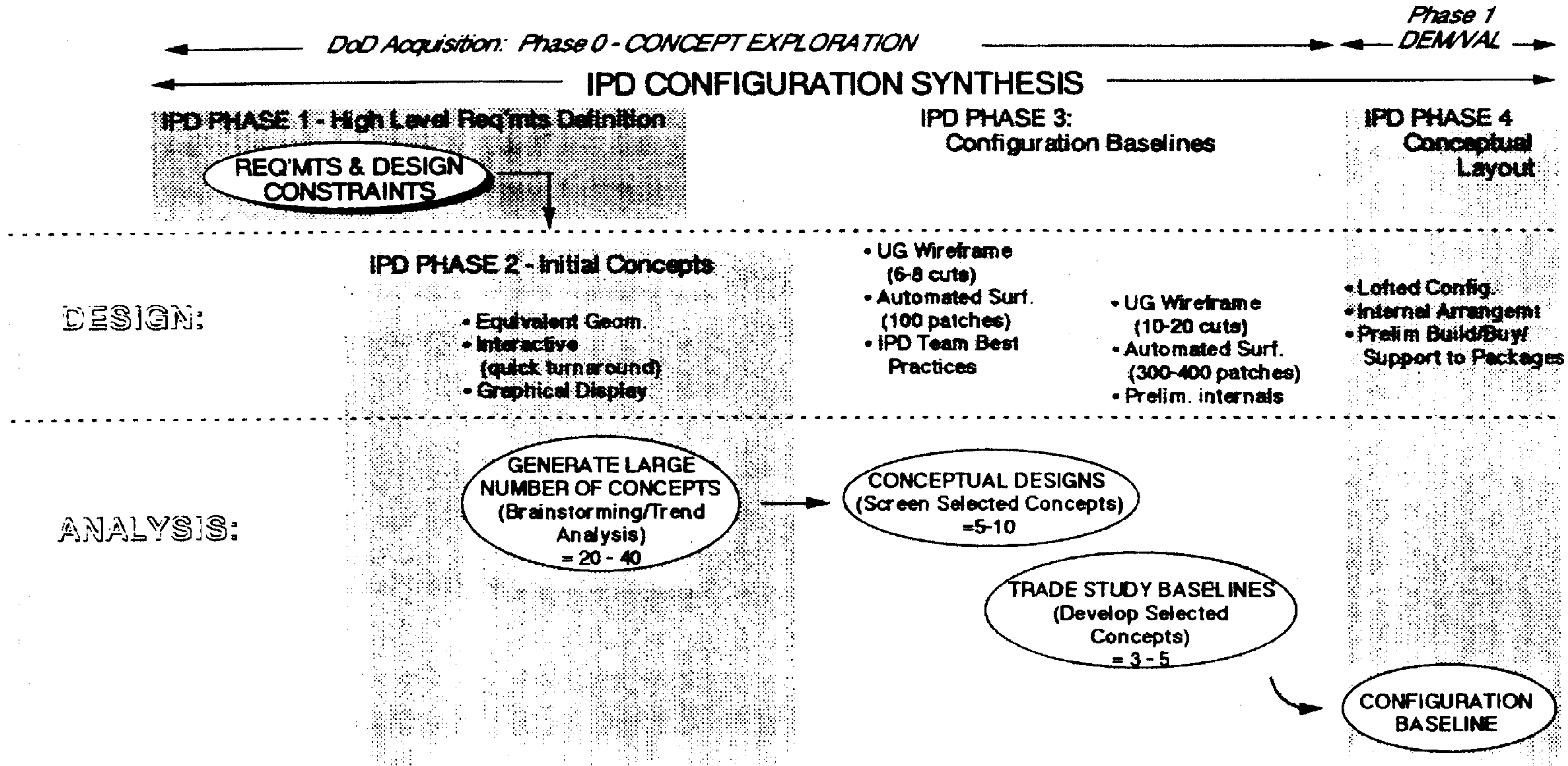
TASKS FOR IMPROVING PREDICTION CAPABILITY

- **Government/Industry survey of needs & requirements**
- **Develop plan and prioritize requirements.**
- **Research capability available in existing methods**
  - Methodology that has proven successful
  - User Interface
- **Literature search to determine scope of empirical database**
  - Aircraft programs
  - Basic research (University, Government Labs, Contractors)
  - Company funded IR&D
- **Additional wind tunnel testing to fill in "holes" in empirical database**
- **Determine methodology to best meet goals**
  - Theoretical vs Semi-Empirical
  - New code and/or Start with existing methods
- **Code Development**
  (Documentation, User Interface, Graphics, Portability, Language, etc.)
- **Validation**

SUMMARY

- Improved Non-linear Aerodynamic Prediction Tools Are Needed To Improve Preliminary Design Capability & Quality
- Aero Predictions Should Support More Than Traditional, Limited Data To Improve Configuration Design
- Priorities For Tool Development Should Be Based On Current & Anticipated Design Challenges
- User Interface, Documentation, And Portability Are Very Important
- LFWC Has A Broad Wind Tunnel Database That Is Well Suited For Development Of Empirical Trends.

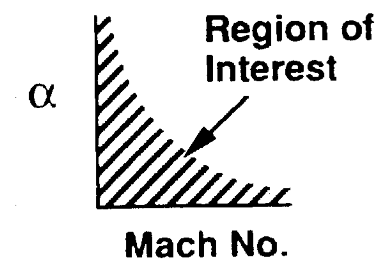
CONFIGURATION SYNTHESIS PROCESS FLOW



Integrated Processes/Tools Provide Configuration Baseline Selection Audit Trail

Basic Requirements for Initial Concept Synthesis

- Lift, Drag Components (C_{D_o}, C_{D_i}), Trimmed Polars



- Estimates of : $\frac{C_M}{C_L}$, C_{L_α}, $C_{L_{max}}$, C_{M_α}, C^*_M, C_{n_β}, C_{l_β}

- Dynamic Derivatives: C_{M_q}, C_{l_p}, C_{n_r}, C_{l_r}, C_{n_p}

- Control Power Effectiveness Estimates for High AOA

- Geometric Versatility (e.g., Blended Wing/Body, Chined Forebody, Flying Wing, etc.)

Configuration Synthesis Process Flow

Req'mnts Definition	Initial Concepts	Configuration Baselines		Conceptual Layout
	20-40 Concepts	**5-10 Concepts**		***Configuration Baseline***
	Aero Analysis Turn-Around Tolerance:			
	1 Minute	1 Hour	1 Week	1 Month
	Geometric Definition:			
	Basic Planform	Wireframe	CAD Surfaced Moldline	Lofted Configuration Internal Arrangement

NASA LaRC / MDA Agility Design Study

Sponsor: NASA Langley - Vehicle Integration Branch
Period of Performance: Dec '92 - Sept '93

Configuration Study Matrix

OBSERVABLES	AGILITY: Low	Medium	High
Conventional (Type A)		Nine Configurations	
Moderate (Type B)			
Low (Type C)			

Controls and Technologies

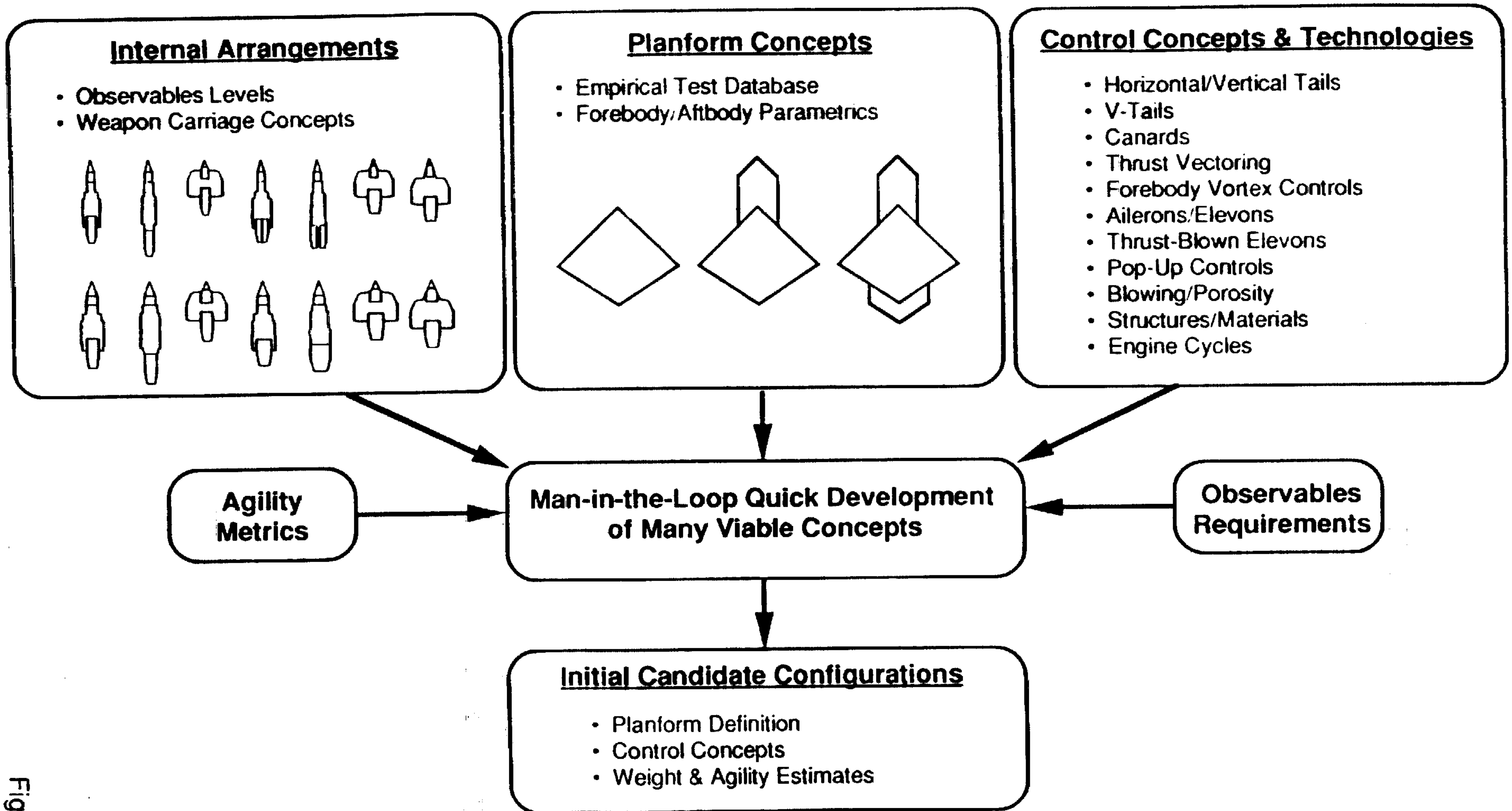
- Aerodynamic Controls (Canards, etc)
- Thrust-Vector Control (TVC)
- Advanced Aerodynamic Controls
- Advanced Propulsion Controls
- Variable Geometry Wings/Controls
- High-Rate Fixed-Aperture TVC
- L.O. Carriage of Ext. Conv. Stores

Products: 1 Agility Design Guidelines
2 Impact of Agility on Design Decisions

LARC92-010E

Figure 1.0.1

Initial Candidate Concept Development



LARC93-146

Figure 4.1.9

Empirical Non-Linear Aerodynamics for Design (ENLAD)

Key methodologies in ENLAD program:

Empirical ADWT-based Non-Linear Longitudinal Aerodynamics (0-80° AOA)
Wide Variety of Wing Planforms in Database (ADWT 192/205/216)
Empirical Non-Linear Longitudinal/Lateral/Directional Control Powers (0-80° AOA)
Horizontal Tails, V-Tails, Vertical Tails (all-moving, ruddered), Canards, Elevons, Ailerons, Thrust Vectoring, Thrust-Blown Elevons, Advanced Forebody Controls

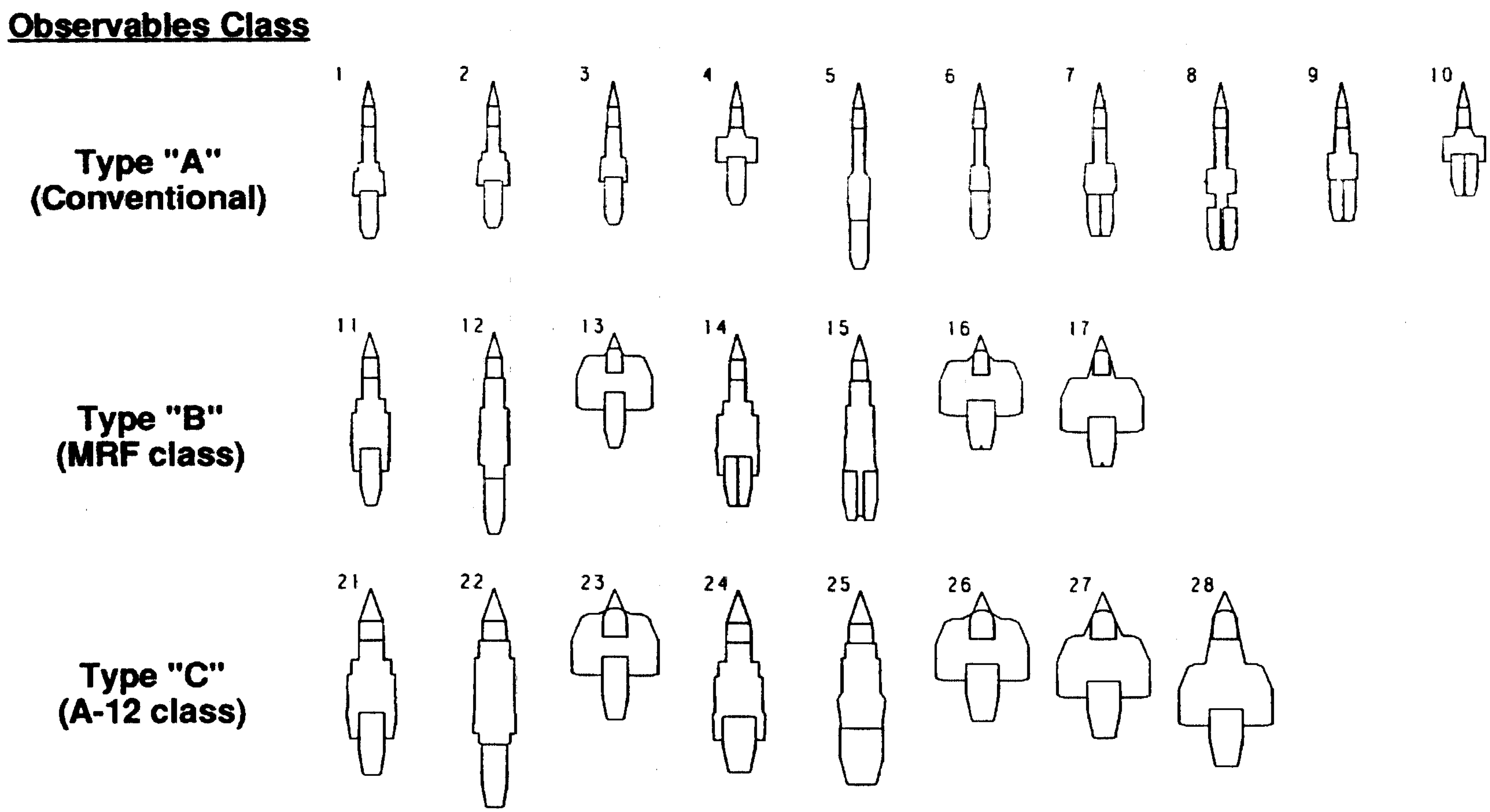
2-DOF Roll-and-Capture Simulation with Pilot Model - Sizes Lat/Dir Controls
Internal Arrangements (Moldline Requirements, Profile Area)
Empirical-based C.G. and Inertia Prediction (Ixx, Iyy, Izz)
Roll-Damping Estimation using DYNAMIC methodology (0-80° AOA)
Roll and Yaw-due-to-Sideslip Estimation at Low AOA
Empty Weight Estimation using MDC A9073 Methods
Trimmed Drag Polar Through Max CL, Bleed Rate vs Turn Rate

What it cannot do:

High Angle-of-Attack Lateral/Directional Stability / Departure Criteria
High-Lift Devices (Slats, Slotted Flaps, etc)

LARC93-022

Candidate Internal Arrangements

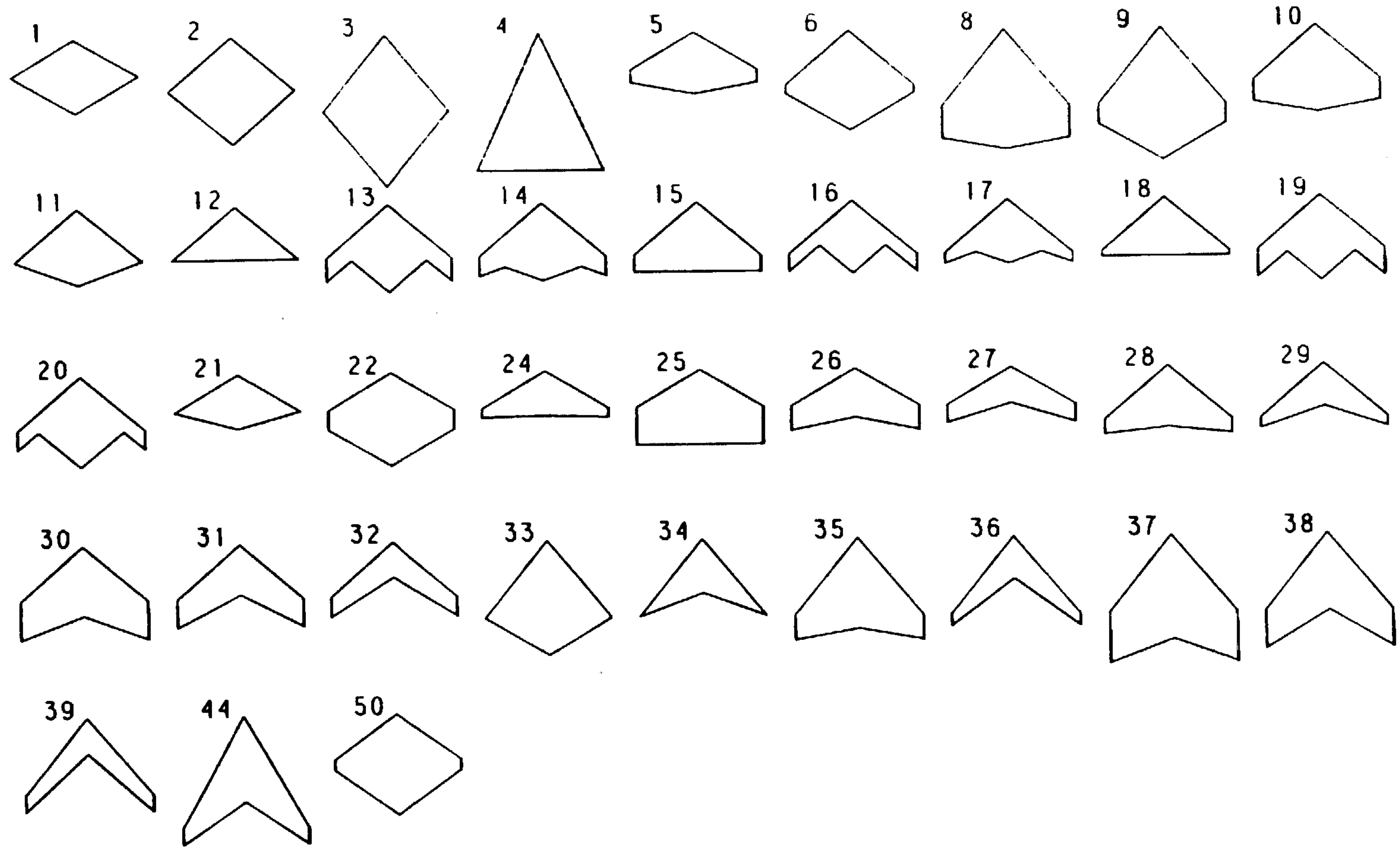


Payload: (2) GBU-24 + (2) AIM-9 (A-G), or (2) AIM-120 + (2) AIM-9 (A-A)
Observables Class Impacts Moldline Requirements and Weapons Carriage
Provisions for Cockpit (F/A-18), Payload, Landing Gear, Inlet, Engine(s) and Nozzle

LARC93-011

Wing Planforms Available in Database

- Wide Variety of Sweeps, Aspect Ratios, and Taper Ratios
- Database Includes Lift, Drag, and Moment at 0-80° AOA



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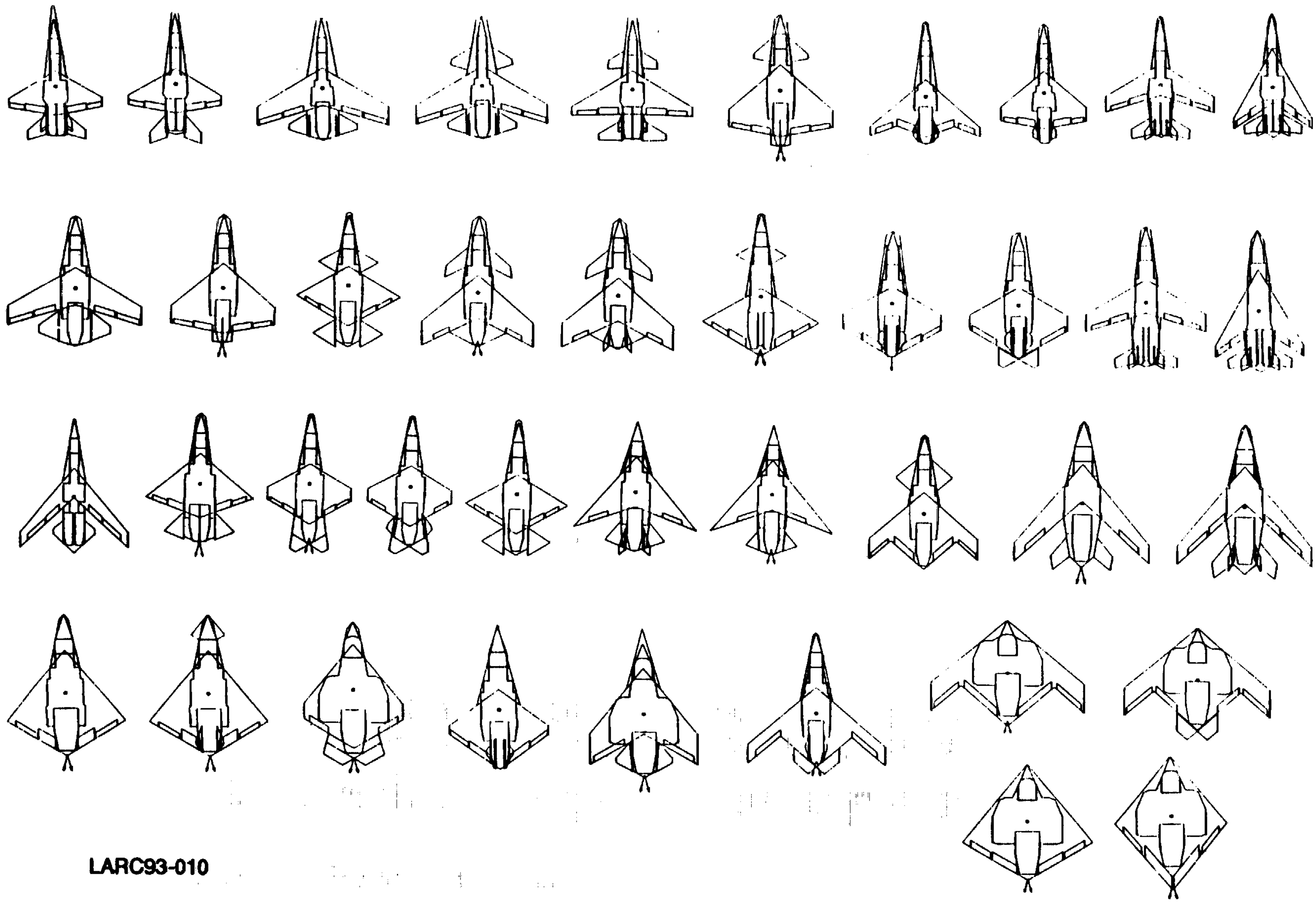
Initial Set of Candidate Configurations



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Miscellaneous Issues

- **Tools Must be Modular:**
  - Stand-alone Capability for Isolated Usage (Proprietary Programs)
  - Appropriate Hooks for Workstation Integration
  - Upgrade Potential
  - Transportability (e.g., Standard Geometry)

- **Linear Analysis Tools are Well-Proven for Linear Aerodynamics**

- **To Address Nonlinear Aerodynamics:**
  - Short Term: Empirical / Semi-Empirical Techniques
  - Long Term: CFD Codes That Have Been Validated and Calibrated in Relevant Applications

- **Possible Role for <u>Careful</u>* Use of:**
  - "Enhanced" Linear Tools (e.g., Vortex Lattice Plus Vortex Model)
  - Full-Potential / Euler Codes Within Workstation Environment

*Applications for which the Underlying Theory is Valid

- **High-Payoff Development Issue:** Incorporate Vehicle Response Models into Early Stages of Concept Synthesis Process

Nonlinear Aero Prediction Methods

Needs

- All Static Coefficients
  - Longitudinal
  - Lateral / Directional
  - Control
  - Drag
- Dynamic Derivatives for Maneuver Performance
  - C_{mq}
  - C_{lp}, C_{lr}, C_{np}, C_{nr} (or $C_{l\omega}$, $C_{n\omega}$)
- Accuracy
  - 20% for Stability and Control
  - 10% for Performance

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B-2 Division

a-2

Nonlinear Aero Prediction Methods

Areas of Concern

- Potential Configurations are Complex
  (Multiple Component Interactions Need to be Modeled)
- Wide Variety of Control Effectors
  (Tails, Canards, T.E. Controls, Etc.)
- Empirical Methods Usually Poor Outside Data Base
  (Concentrate on Fighter/Attack Configurations)

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Nonlinear Aero Prediction Methods

Maximize Utility

- Internal Trim Calculation Not Required
  - Better Done Independent of Predictive Methods
- Sizing/Optimization Not Required
  - Multiple Parameters/Figures of Merit
- Effort Should Concentrate on Subsonic Speeds (to M ~ 0.9)
  - Transonic (M ~ 0.9 to 1.2) too Complex
  - Little Need for Nonlinear Effects Supersonically (except Aeroelastic)
- Method Should be Useful for Predicting Trends Due to Component Perturbations
  - Lex Size/Shape Variation
  - Tail Size
  - Planform
  - Etc.
- Hinge Moment Prediction Would be Valuable

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Nonlinear Aero Prediction Methods

Operating Considerations

- Should be Operable on Work Station (Silicon Graphics/Unix)
- Input For Complete Configuration 1-2 Days Max.
- Simple Input for Flat Planforms with Controls
- 1 Day Max Run Time
- Tabular, Plotted, Electronic Output

Nonlinear Aero Prediction Methods

Parametric Data Base

- Low Speed Data
- Flat Plate Models With Controls
- Controls Include: Flaps, Ailerons, Drag, Rudder, and All-Moving Tails
- Delta and Modified Delta
  60 - 75 Deg. L.E. Sweep
- Parallel Edge Wing - Tail
  30 - 55 Deg. L.E. Sweep
- Parallel Edge Wings
  50 - 70 Deg. L.E. Sweep

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Nonlinear Aero Prediction Methods

Configuration Specific Data Base

Configuration	Data	Comments
F-5	Low Speed, High Speed, Rotary Balance	
YF-17	Low Speed, High Speed, Rotary Balance	
F-20	Low Speed, High Speed, Rotary Balance	
YF-23	Low speed, High Speed, Rotary Balance, Spin	Data Confidential
NATF	Low Speed, High Speed, Rotary Balance	Data Confidential
B-2	Low Speed, High Speed Rotary Balance	Data Confidential
OCS	Low Speed, High Speed	Control Concept Evaluation
Arrowhead	Low Speed	AX Candidate, Data Proprietary
ATA	Low Speed, High Speed	Configuration, Data Classified

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ASC/XRED - Aerodynamics in Conceptual Design

Must be responsive to quick geometric changes

Must not require detailed geometry (Datcom type code)

Must run on workstations or equivalent PC's

Run times in minutes not hours

Trend information more important than absolute accuracy

Understanding "why" more important than "what"

ASC/XRED - Stages of Conceptual Analysis

	Stage 0	Stage 1	Stage 2	Stage 3
Lift & Drag	X	X	X	X
Moment & Trim		X	X	X
Long. control			X	X
Lat - dir control				X
High - lift			X	X
Concept stage	Vehicle Size	Maneuver Boundaries	Move from concept to detailed layout	
% of time stage reached	100	90	20	5

ASC/XRED - Present Trends

Faster computers allow more in depth analysis

Signature requirements demand higher level aero analysis

Movement away from empirical toward vortex lattice type methods

More emphasis in high-lift effects

WL/FIMA recent experience with aero codes

Code	Configurations	Experience	Comments
APAS	Tailless Fighter, Adv. Supersonic Fighter, FDL Beta, CTOL Fighter	Good/Excellent	Complex Geometry Still Tektronix Based
AERO2S	CTOL Fighter	Fair/Good	Simple Inputs, 2-Surface Flap Analysis
D. Datcom	Tailless Fighter, Adv. Supersonic Fighter ...	Good	Simple Geometry
VSAERO	Tailless Fighter, Adv. Supersonic Fighter, FDL Beta, Flying Wing ...	Fair	Complex Geometry, Subsonic Only
USAERO	Adv. Supersonic Fighter, Delta Wings	Poor	Complex Geometry, Unstable solutions, Subsonic Only
VLM	Tailless Fighter, Adv. Supersonic Fighter, FDL Beta, CTOL Fighter		Simple Inputs Subsonic Only
WINGDES2	CTOL Fighter	Good	Simple Input Wing Camber Design Code

WL / FIGC recent experience with aero codes

Code	Configurations	Experience	Limitations
D. Datcom	C-17, NKC-135, VISTA, Adv. transport, F-18, ...	good	no lat-dir high AOA no adv. configs
M. Datcom	Tailless fighter, NKC-135, Adv. transport, AGM-136, SRAM II, BLU-109, ...	v. good	no roll, yaw dynamics limited control devices
Dynamic	VISTA, X-29, T-46	good	no statics requires loads data
HASC	VISTA, F-15, Adv. transport	fair	subsonic only doesn't always work
PMARC	F-15	poor	time consuming no solutions
SCHV/HABP	FDL Beta, Shuttle	good	high speed only
VORLAX	VISTA, X-29, T-46, F-18	good	limited non-linear effects
VORSTAB II	VISTA, X-29, C-17	poor	time consuming unstable solutions
VSAERO	F-15	good	time consuming

WL / FIGC experience with code development

Our primary products are the Datcom codes:

Digital Datcom (1976), updates 79, 83, 90

Missile Datcom (1985), updates: 89, 91, 93

We have also been involved with the development of:

Dynamic, JETIGE, VORSTAB, HASC, and HABP (SCHV)

Developing a code is one thing; maintenance, upgrade, and user interface require significant effort and must be centralized.

WL/FIGC code plans (updates)

SCHV

Inlet / nozzle code updates near completion, Feb 94 availability

Missile Datcom

Improved high AOA carryover factors (FY94 test planned)

Improved fin vortex model, roll damping (planned, FY95)

HASC

Configuration plot capability available (TEKPLOT compatible)

Interactive input module near completion

Three year Ga. Tech study underway (AFOSR)

- Developing vortex burst / interaction data base
- Correcting code errors

Improved body vortex capability (planned, funding not identified)

WL / FIGC assessment of what we need

What can't we do or do well with current design codes :

- Nose vortex control devices
- Novel control devices
- Ordinary control devices at high AOA
- Chined forebodies
- Dynamic derivatives at high AOA
- Propulsion induced effects (especially STOVL)

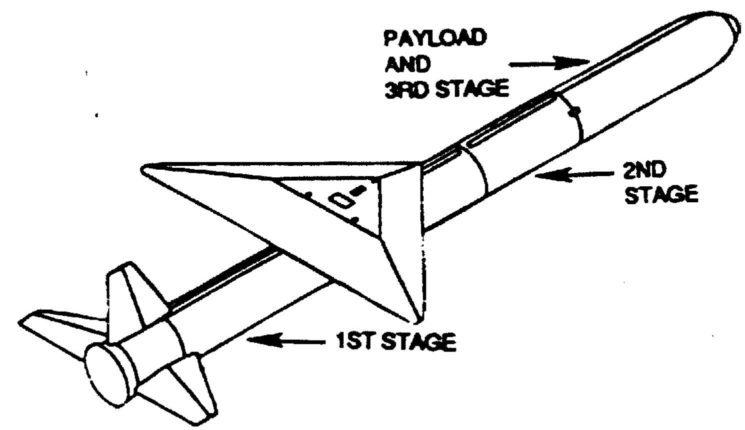
A large data base exists that addresses many of these concerns

An empirically based code may be a promising solution

Prediction Code Success Story

<u>*April 5, 1990*</u>

Pegasus successfully placed two satellites into orbit



Pegasus was never wind tunnel tested.

It was designed using engineering prediction codes:

Missile Datcom, MISL3, and SHABP (MADM)

Cost saving estimates range from $250K - $2M

Pegasus is built by a team led by Orbital Sciences Corporation

Aerodynamic analysis was performed by Nielsen Engineering & Research

Lockheed Aeronautical Systems Company

Charles Adler

Stability and Flight Controls Department

Methodology - Basic Capabilities

1.) CL, CD, CM

2.) CY, Cn, Cl

3.) alpha and beta derivatives

4.) p, q, r derivatives

5.) alpha dot derivatives

Nonlinear Aero Prediction Requirements Workshop

Methodology - Basic Capabilities

Additional Capability:

Loads Prediction - Cp's, AIC Matrices

Finite Element Models are being used
Earlier Than Ever - Loads Prediction is
Probably the Weakest Link in Preliminary Design

Methodology - Basic Capabilities

Additional Capability:

Propulsion Effects

- Affects Sizing and Placement
- Increasingly Important with Increasing Integration

Methodology - Basic Capabilities

Priorities

1.) Loads - Cp's, AIC's

2.) Drag

3.) S&C

4.) Propulsion Effects

Methodology - Speed Range

In Order of Priority

1.) Transonic

2.) Supersonic

3.) Subsonic - High Angle-of-Attack

4.) Subsonic

Methodology - Sizing Capabilities

Desirable, but:

- No Black Boxes
- Keep Basic Method as Simple and General as Possible - Sizing Routines as a Standalone Module

Methodology - Run Time

Loads: 1 - 2 Hours per Flow Condition on a

S&C: 2 - 4 Hours per Derivative Set (at a given Mach)

Drag: 1 - 2 Hours per Polar

Methodology - Input, Setup Time

Basic Panel Method Input
  No Volume Grids

Option for Simpler Geometry (Flat Plate)
Would be Useful

Setup Time - From 1 to 3 days maximum

Methodology - Program Structure

A Stand-Alone with High Modularity

- If it is good it will be integrated into design synthesis tools
- Will be used (and proven) first as a stand-alone tool

LASC

Nonlinear Aero Prediction Requirements Workshop

Methodology - Output

Overall Force and Moment Summaries

Pieces to Various Forces
(i.e. Vortex Lift, Induced Drag, etc...)

Component Force and Moments - including Hinge Moments (Vertical Tail, Rudder, Aileron, etc...)

AIC Matrix, By element Cp's

Methodology - User Interface

GUI (X-window etc...)

Interactive Geometry Editing & Output Viewing (similar to CFD methods)

Sophisticated Interface can be Sacrificed for Portability

LASC

Nonlinear Aero Prediction Requirements Workshop

Methodology - Integrating / Scaling Data

Very Important Feature

Establishing Sound Guidelines in this area
Would be a Significant Contribution by Itself

Scaling Existing Loads Data (Pressure Distributions)

High Angle-of-Attack Data Integration

Leading Edge Suction Schedule Development
Across the Mach Range

Methodology - Analytical versus Empirical

CL, Cm - Semi-Empirical High AoA:
Suction Analogy with CLmax

CD - Semi-Empirical Suction Prediction
Empirical Vortex Drag Prediction

CY, Cn, Cl - Empirical High AoA

Derivatives - Empirical High AoA

Data Base - Parameters

Flow

Reynolds #, Mach #, Shock and Vortex Locations, Burst and Separation Locations

Geometry

Wing & LEX: LE & TE Sweep, Section, Leading Edge Shape, Twist, Breaks

Fuselage:

Forebody Finess Ratio, Shape, and Camber

Chine Position, Camber, Chord, and Sharpness

Afterbody Camber, Thickness, and Shape

Data Base - Contents

- Flow Data
- Force and Moment Data
- Component Breakdown Force and Moment Data
- Detailed Geometry Descriptions
- Pressure Data
- Flow Visualization Summaries

Data Base - LASC Data Availability

Modern Fighter

F-22 Team;

YF-22 25,000 Test Hours
F-22 15,000 Test Hours

Majority Available on Electronic Media

Data Base - LASC Data Availability

Transport

C-130, C-141, C-5

30,000 + Hours of Wind Tunnel Testing

~ 50% of that on Electronic Media

Validation - Benchmark Suite

- A Next Generation Combat A/C - YF-22, F-22, YF-23, AX and a Current Generation Combat A/C F-14, F-15, F-16, F-16XL, YF-17, F-18, HARV X-29, X-31, and an HSCT Configuration

  - o Force and Moment
  - o By Component Breakdown (Incl. H.M.)
  - o Pressure Data
  - o Some Parametric Geometry Variation
  - o Subsonic, Transonic, and Supersonic Points
  - o High AoA at Subsonic

Nonlinear Aero Prediction Requirements Workshop

Validation - Benchmark Suite

- Simple Wings (Compare with CFD?)
  - o Transonic Loads
- Delta Wings, Chined Forebodies
  - o High AoA Forces and Moments
  - o Vortex Prediction

Validation - Level of Accuaracy

- ~ 5% Standard Aero (CL,Cm,CD)
- ~ 10% Lat/Dir & Derivatives
- ~ 15% High AoA, Transonic

- Quality of Test Data Used for Validation Should be Quantified

Summary

- o Loads is a Conceptual/Preliminary Design Concern
- o Propulsion Effects are Needed Early in Process
- o A Tremendous Experimental Data Base is Available and Should be Exploited
- o Keep it Simple and Fast

II. Panel Discussion - Methodology Requirements

A panel discussion was held to summarize the points made during the presentations regarding what a proposed method should do. There was considerable variation in prioritizing desired capabilities. The differing needs of the organizations and functional disciplines represented at the workshop were voiced in the comments below. A summary of these requirements can be found in Figure 2.1.

Presently there is no way to "screen" candidate configurations with respect to non-linear aerodynamics characteristics. Therefore, a desirable element of the proposed methodology would be a rapid, empirical method that uses primarily parametric input to represent the vehicle configuration. This element would be integrated into closed-loop design synthesis tools currently in use within the industry. As such, the run time for the method should be less than 1-2 minutes and should be usable on either PC or workstation class computers. This portion of the method, referred to as "Mode 1" should compute elements such as trimmed C_L, C_D, C_M, *vs* α up to and including stall regions for "clean" and "high-lift" configurations, ΔC_M for control effectors in all axes, C_m^* point (if appropriate), and "departure point" or other boundaries/limits to the stability and/or control envelopes.

Beyond screening and performance related aero predictions, a need exists to generate more detailed aerodynamic characteristics to a reasonable level of accuracy without resorting to manpower and computationally expensive high-order methods. A semi-empirical / semi-analytical method is desired which would use CAD-like geometric surface definitions to compute detailed aerodynamic parameters such as force and moment coefficients and pressure distributions by component, longitudinal and lateral/directional coefficients and derivatives, flow-field and interference effects (such as vortex tracking), control effectiveness and the parameters computed in the Mode 1 method to a higher degree of confidence. Runtime expectations varied but generally a runtime of 4 hours on a workstation to compute all the desired information for a reasonable set of Mach numbers and angles of attack was considered acceptable. Setup time should be limited to one week, assuming the user has to create the input geometry manually, less if a direct link to CAD files is implemented. Also assumed was that a graphical user interface would exist to allow ease of use for setup, run, and post processing/flow visualization.

An important consideration is that both forms of the method should be able to compute aerodynamic parameters in all speed regimes from low subsonic to moderate supersonic. Also important would be the ability to compute data from 0 - 90^o angle of attack and +/- 10^o in sideslip.

Additional discussions concerning development aspects indicated potential areas of concern. Presently, most graphical routines are developed in C, and most analysis routines are developed in FORTRAN. Further study will need to address the issue of appropriate language for the methods. Other comments expressed involved the need for appropriate documentation. It was felt that three forms of documentation would be

necessary: a User's Manual, a Methodology Description Manual describing how the methods were derived and source data bibliography, and a validation report. Also expressed was the need for a tutorial and/or training package.

Figure 2.1 - Summary of Methodology Requirements	
Mode 1 - Empirical Method	-Rapid solution time (< 1-2 minutes) -Minimal Parametric Input -Can be made part of closed loop synthesis -Calculate trimmed C_L, C_D, C_M, vs α up to and including stall regions -Compute ΔC_M for control effectors in all axes -Compute clean and high-lift conditions -Compute departure points and/or boundaries -Speed range from low subsonic to moderate supersonic -Alpha range from 0-90, Beta +/- 10 degrees
Mode 2 - Semi-Empirical / Semi-Analytical Method (SESAME)	-Run times of ~4 hours (on workstation) -Panel / CAD surface geometry input -Compute Mode 1 data -Compute force/moment coefficients by components -Compute Cp distribution -Compute longitudinal and lateral / directional coefficients and derivatives -Computes flow field (e.g. vortex) and flow interference effects -Compute control effectiveness -Speed range from low subsonic to moderate supersonic -Alpha range from 0-90 degrees, Beta +/- 10 degrees

III. Panel Discussion - Data Base Development

(An opening presentation was made by Mike Logan of NASA LaRC and is included following this text.)

A panel discussion was then held to identify more clearly the needs of industry engineers and researchers in identifying and using technical information such as wind tunnel and flight test data. The participants expressed the current information access systems are insufficient to make effective use of the vast data storehouse within the industry. Specifically, there is presently no way to uniquely locate a source document which may contain data for a particular configuration under consideration.

The participants felt that a "multi-media", CD-ROM index, with a knowledge-based multi-path search facility, allowing the user to interactively search for wind-tunnel, flight, and computational test data would be an invaluable resource to the research and engineering communities. Contents of such an index should include a description of the geometry of the item tested, the conditions of the test, what parameters were measured, a summary of the test and results found, points of contact, and bibliography of the report(s) associated with the test.

The participants also felt that it was important that the index be searchable both by geometric parameters (e.g. wing aspect ratio, forebody shape, etc.) and by specific topics (e.g. "tiperons"). A given test might generate several entries into the index since a test may be a multi-component model test. Furthermore, several documents may be indexed to a single geometry entry (if a model was tested several times, for example). One suggestion to make the search capability as flexible and powerful as possible was to incorporate an expert system search as part of the tool. Another suggestion was to have a central repository for the source documents referenced by the index so the user need only contact one place to obtain the data. Possibilities include using the NASA Library or perhaps one of the Government repositories.

Concerns were expressed during the discussion concerning the breadth of the index. It was felt that the index should reference current reports and begin going back as time and money allow. There was a discussion about how far back to include index data. Certain areas might need to access data that is very old whereas some data is only very recent. In addition, it is felt that a classified version of the index needs to be available. It was felt that annual or semi-annual updates would be necessary to keep the index "current".

A concern on the part of the participants was proprietary data and how it should be handled. The breadth of data available must be as expansive as possible in order for the index to be most useful. However, issues relating to competitive advantage must also be addressed. One element of this consideration involves many of the cooperative tests conducted in Government wind tunnels. No resolution to these issues was reached other

than it is assumed that companies would most likely have to be compensated to put references to their data into the index.

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NON-LINEAR AERO METHODS

DATA BASE NEEDS - GENERAL TOPICS

IDENTIFICATION OF NEED:

- ABUNDANCE OF DATA AVAILABLE
- NO USEFUL WAY TO ACCESS DATA EXISTS
- NO SINGLE CATALOG OF DATA INDUSTRY WIDE

KEY FEATURES:

- INTERACTIVE, MULTI-MEDIA SEARCH CAPABILITY
- DATA BASE ACCESSABLE USING GEOMETRIC PARAMETERS
- INDEX TO RELEVENT DOCUMENTS
- DATA INPUT FROM A VARIETY OF SOURCES
- DATA MUST INCLUDE RELEVENT PARAMETERS

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NON-LINEAR AERO METHODS

DATA BASE NEEDS - OTHER IDEAS

ACCESS:

- CD-ROM PARAMETRIC/GRAPHICAL INDEX TO REPORTS
- SEARCH CRITERIA SHOULD INCLUDE:
  - CONFIGURATION GEOMETRY PARAMETERS
  - TEST CONDITIONS
  - SOURCE AND/OR FACILITY
- HAVE CLASSIFIED VERSION OF INDEX AVAILABLE

SOURCES:

- WIND TUNNELS - NASA-LaRC, ARC, LeRC, AF-AEDC,WL NAVY-DTRC,etc., INDUSTRY, UNIVERSITIES
- FLIGHT TEST - AF-EAFB,NASA-DFRF,NAVY-NAWC

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NON-LINEAR AERO METHODS

DATA BASE NEEDS - OTHER IDEAS (Cont'd)

CONTENT:

- CONFIGURATION GEOMETRY - PARAMETRIC TEXT AND GEOMETRIC IMAGE (3-VIEW + MODEL IMAGE)
- TEST CONDITIONS - MACH, Rn, α, β
- SOURCE AND/OR FACILITY
- MEASURED QUANTITIES
- GRAPHICS SUMMARY AND/OR FLOW VISUALIZATION ?
- BIBLIOGRAPHY

SCOPE OF DATA:

- HISTORICAL INDEX OF LAST XX YEARS
- UPDATED ANNUALLY

III. Panel Discussion - Validation and Accuracy

The objective of the validation and accuracy panel discussion was to identify a "reasonable" validation suite of configurations and clarify how the development team would know they had succeeded in developing a tool considered by the industry to be accurate enough for "production" use. From that perspective, the panel discussion was successful with the summary of the findings found in Figures 3.1 and 3.2.

The participants agreed that a small, representative validation suite would be necessary. It was pointed out that for certain parameters, such as performance aero, flight test data would be the most appropriate data source. For other parameters, such as control effectiveness at high angles of attack, wind-tunnel test data would be the best source. As can be seen in Figure 3.1, full configurations, component buildups, and control device test data will be needed to test the relevant capabilities of the tool. Comparisons between the tool and the test data will have to be matched to similar flow conditions so that appropriate inferences can be drawn about accuracy.

As a part of the validation, the strengths and weaknesses of the code should be identified. Furthermore, it was felt by the participants that the developers as well as new users should be involved in the validation.

There was a significant level of agreement that certain parameters needed high levels of accuracy. For example, basic aero performance parameters in the subsonic region needed a high confidence level. However, for certain stability and control parameters, the most important facet of the tool's ability would in fact be that the sign of the parameter was predicted correctly (e.g. stable vs. unstable) rather than the magnitude being within some arbitrary tolerance. Achieving a consensus among the participants concerning "acceptable" accuracy was difficult. Compunding this difficulty was that the concept of accuracy for a parameter that alternates around zero being ill-defined. One proposed solution was that a "percentage error" be applied to the range of variance for the parameter (e.g. if a parameter varies as a function of angle-of-attack from -1 to +1, a 5% error would mean +/- 0.1). Other accuracy criteria were proposed that would relate to a resulting design parameter or target value like C_m^* value and angle of attack where it occurs. These multiple accuracy criteria are considered necessary since there is little meaning to a single number when referring to the multitude of types of parameters being estimated. Again, a summary of the desired accuracy by type of parameter and type of flow conditions sought are found in Figure 3.2.

Figure 3.1 Validation Suite - Configurations/Data Required	
Flight Test Data	F-16/F-18 Class vehicle (current generation fighter) YF-22/YF-23 Class vehicle (next generation fighter) F-16XL/X-31 (Semi-tailless fighter) Tailless ("Flying Wing" configuration) Flight Condtions: from 30-50 deg. alpha, 0.2< Mach < 0.9
Wind Tunnel Data	"Conventional" Configuration Buildups - Wing-Body-Tail - WBT with strake - WBT with chine forebody - Single/Dual Vertical tail Canard Configuration with buildups Tailless vehicle Control effectors data for above configurations Reynolds number for test must be known, matched to prediction

Figure 3.2 Accuracy requirements				
	Parameters			
Flow Conditions	Performance Aero	Longitudinal Stability/Control	Lateral-Directional Stability/Control	Control Effectiveness
Low Subsonic: Attached flow Partially Separated Fully Separated Flow	 5-10% 10-20% 20-30%	Aft CG within 3%MAC and < 20% of data range	5-20% data band Stability point within 3-5 deg. Correct sign/trend	10-20% Max. Pwr Avail. Ctl. Reversal < 3-5 Deg.
Subsonic: Attached flow Partially Separated Fully Separated Flow	 5-10% 10-20% 20-30%	Aft CG within 3%MAC and < 20% of data range	5-20% data band Stability point within 3-5 deg. Correct sign/trend	10-20% Max. Pwr Avail. Ctl. Reversal < 3-5 Deg.
Transonic: Attached flow Partially Separated Fully Separated Flow	 5-10% 10-20% 20-30%	Aft CG within 3%MAC and < 20% of data range	5-20% data band Stability point within 3-5 deg. Correct sign/trend	10-20% Max. Pwr Avail. Ctl. Reversal < 3-5 Deg.
Supersonic: Attached flow Partially Separated Fully Separated Flow	 5-10% 10-20% 20-30%	Aft CG within 3%MAC and < 20% of data range	5-20% data band Stability point within 3-5 deg. Correct sign/trend	10-20% Max. Pwr Avail. Ctl. Reversal < 3-5 Deg.

Industry Needs Questionnaire:

Purpose:

In order to expedite the identification of the industry's needs relating to conceptual/preliminary design non-linear aerodynamics prediction, please consider your organizations responses to the following questions:

Methodology:

1. What basic capabilities should such a method have?

1a. Should the method be able to predict lift and drag as a function of angle of attack?

1b. Should the method be able to generate moment curves and trimmed polars?

1c. Should the method be able to compute basic stability derivatives? If so, which ones?

1d. Should the method be able to predict lateral-directional as well as longitudinal characteristics?

1e. Should the method be able to generate control power/effectiveness?

1f. Should the method be able to predict dynamic derivatives. If so, which ones?

2. What speed regimes should the non-linear aero method(s) deal with? (Low subsonic, subsonic, transonic, supersonic, etc.)

3. Should the method provide any facilities for "sizing" devices to particular criteria? (E.g. size an aileron to meet a roll criteria)

4. What run time (wall clock) would be considered "acceptable" for the method? What class machine should it be able to run on? How long should it take to perform each of the functions in part 1 above?

5. What form of geometry input should the system use? What set-up time would be considered "acceptable" for a method of this type?

6. Should the method be usable as a stand-alone, interactive analysis tool, or should it be modularized to integrate into an existing design synthesis tool? (Or both?)

7. What kind of output is desired? What kind of user interface is desired?

8. Should it be able to integrate known data and "scale" to the configuration being analyzed?

9. Using the functions desired in part 1. above, which predictions are likely to need analytic solutions and which are likely to need empirical/semi-empirical solutions?

Data Base:

10. If an empirical method is used, what would a reasonable set of categorization parameters be? (For example, what parameters would you need to match between the configuration of interest and a wind tunnel test's configuration in order to determine whether the test data is applicable?)

11. Using the geometric parameters identified in 10, what should a data base consist of that would ensure that sufficient information exists to develop the empirical parts of the methodology?

12. Approximately how much information (i.e. configuration geometry data, test results, etc.) does your organization presently have cataloged? How much of this information could be used to develop predictive methods for the parameters listed in part 1? What percentage of this data is electronic vs. paper, open vs. proprietary vs. classified?

Validation:

13. What should a "reasonable" validation benchmark suite consist of?

14. What level of accuracy would be considered "acceptable" for the parameters listed in part 1.

Responses to these questions should be considered when formulating your organizations requirements. As this list is not comprehensive, feel free to express other relevant concerns/comments. These considerations are merely intended to help stimulate a common framework for the workshop presentations/discussions.

WIND TUNNEL DATA AVAILABLE FROM WL/FIGC

All unclassified, non-proprietary

Configuration:	F-15 S/MTD
Facility:	NASA Lewis 9 by 15 Foot V/STOL Tunnel
Comments:	This test investigated hot gas ingestion and airframe heating for the S/MTD configuration. No force and moment data were taken.
Reference:	Blake,W.,Laughrey,J.A.,"F-15 SMTD Hot Gas Ingestion Wind Tunnel Test Results", AIAA-87-1922, July, 1987.
Data in Report?:	No (tabulated data available)
Data available on Disk?:	No

Configuration:	F-15 S/MTD
Facility:	McDonnell Aircraft 8 by 12 Foot Low Speed Wind Tunnel
Comments:	This test investigated the effects of thrust reverser flow on stability and control characteristics during approach and landing.
Reference:	Blake,W.,"F-15 SMTD Low Speed Jet Effects Wind Tunnel Test Results", NASA CP 10008 pp.91-119, April 1987.
Data in Report?:	No (tabulated data available)
Data available on Disk?:	No

Configuration:	F-15 S/MTD
Facility:	NASA Langley 30 by 60 Foot Full Scale Tunnel
Comments:	This test consisted of static and forced oscillation testing from zero to 90 degrees angle of attack. Limited configuration build-up was performed.
Reference:	Murri, D., Grafton, S., and Hoffler, K., "Wind Tunnel Investigation and Free-Flight Evaluation of a Model of the F-15 STOL and Maneuver Technology Demonstrator," NASA TP 3003, August 1990.
Data in Report?:	No (tabulated data available)
Data available on Disk?:	No

Configuration:	Sharp and blunted circular and elliptical forebodies of various lengths mounted to a circular or elliptic fuselage. Limited data for configurations with a 50 degree clipped delta wing and vertical tail.
Facility:	NASA Langley Research Center 20-Foot Spin Tunnel (rotary balance test)
Comments:	This rotary balance test investigated the effect of various forebody shapes and modifications to forebodies (strakes, chines, inclined forebodies) on the static and rotary characteristics of the configuration.
Reference:	Bihrle,W.Jr,Barnhart,B.,Dickes,E.,"Static and Rotational Aerodynamic Data From 0^{o} to 90^{o} Angle of Attack for a Series of Basic and Altered Forebody Shapes", WRDC-TR-89-3090, September 1989. (DTIC Number: ADA 55919)
Data in Report?:	Yes
Data available on Disk?:	No

Configuration: NASA Generic Fighter Model (fineness ratio 4 ogive nose, cylindrical body, 45 deg. swept wing with LEX, horizontal and vertical tail. alternate configuration: 30 deg. forward swept wing with small canard.)

Facility: NASA Langley Research Center 12-Foot Low Speed Wind Tunnel

Comments: This test investigated various vortex control devices including forebody strakes, forebody blowing, Leading Edge Extension (LEX) blowing, LEX flaps, etc. Circular and elliptical ogive forebodies were tested. Part of the test included a separate balance used to measure forces and moments due to the forebody.

Reference: Malcolm,G.N.,Lewis,L.C.,Ng,T.T.,"Development of Non-Conventional Control Methods for High-Angle-of-Attack Flight Using Vortex Manipulation", WL-TR-91-3041, June 1991.
(DTIC Number: ADB 159428)

Data in Report?: No

Data available on Disk?: Yes

Configuration: USAF Generic Tailless Fighter (three wing planforms, 50 deg delta, 50 deg diamond, and 50 deg parallel leading/trailing edge were tested on a circular body with 2 noses.)

Facility: Wright Laboratory Subsonic Aerodynamic Research Facility (SARL)

Comments: This test investigated a series of control effectors on a generic tailless fighter configuration. Six component force and moment data were taken. A wide variety of control devices were tested including plain flaps, split flaps, spoilers, clamshell elevons, all movable wing tips, leading edge flaps, etc.

Reference: Baldwin,W.A.,Adamczak,D.W.,"Experimental Evaluation of Aerodynamic Control Devices for Control of Tailless Fighter Aircraft", WL-TM-92-318, April 1992.
(DTIC Number: ADB 164505L)

Data in Report?: Yes

Data available on Disk?: Yes

Configuration: NASA Generic Fighter Model (fineness ratio 4 ogive nose, cylindrical body, 45 deg. swept wing with LEX, horizontal and vertical tail.)

Facility: University of Kansas Low Speed Wind Tunnel.

Comments: This test investigated the influence of forebody vortex separation location on the forces and moments. Data includes forebody and configuration force and moment data for smooth forebodies and for forebodies with separation points fixed by the addition of forebody strakes. Oil flow surveys were conducted on the smooth forebody.

Reference: Adler,C.O.,Dixon,C.J., "High Angle of Attack Stability and Control - Wind Tunnel Test Report", WL-TR-92-3051,September 1992.
(DTIC Number: ADB 170009)

Data in Report?: Yes

Data available on Disk?: No

Configuration: F-16/VISTA
Facility: Ohio State 14 by 16 Foot Low Speed Tunnel
Comments: This test investigated the effects of various modifications on the longitudinal and lateral/directional characteristics of the F-16/VISTA configuration. Various nose chines, modified speedbrakes, and a cut back LEX were tested.
Reference: Simon,J.M.,LeMay,S.,Brandon,J.M.,"Results of Exploratory Wind Tunnel Tests of F-16/VISTA Forebody Vortex Control Devices", WL-TR-93-3013, January 1993.
(DTIC Number: ADB173153)
Data in Report?: Yes
Data available on Disk?: Yes

Configuration: F-16/VISTA
Facility: NASA Langley Research Center 30 by 60 Foot Full Scale Tunnel.
Comments: This test investigated the effects of various modifications on the longitudinal and lateral/directional characteristics of the F-16/VISTA configuration. Various nose chines, modified speedbrakes, and a cut back LEX were tested.
Reference: Simon,J.M.,LeMay,S.,Brandon,J.M.,"Results of Exploratory Wind Tunnel Tests of F-16/VISTA Forebody Vortex Control Devices", WL-TR-93-3013, January 1993.
(DTIC Number: ADB173153)
Data in Report?: Yes
Data available on Disk?: Yes

Configuration: F-16/VISTA
Facility: NASA Langley Research Center 20 Foot Spin Tunnel
Comments: This was a rotary balance test of the F-16/VISTA configuration with modifications. Various nose chines, modified speedbrakes, and a cut back LEX were tested. A limited amount of forebody blowing was tested as a nose vortex control device.
Reference: Simon,J.M.,LeMay,S.,Brandon,J.M.,"Results of Exploratory Wind Tunnel Tests of F-16/VISTA Forebody Vortex Control Devices", WL-TR-93-3013, January 1993.
(DTIC Number: ADB173153)
Data in Report?: No
Data available on Disk?: Yes

Configuration: Generic V/STOL Powered Models (60 deg. clipped delta wing with provisions for single or dual, circular or rectangular, lift jets in three axial position. alternate configuration: untapered aspect ratio 4 rectangular and 30 deg. swept wings mounted on body with same lift jet positions)

Facility: NASA Ames Jet Calibration and Hover Test Facility and NASA Langley 14 by 22 Foot Subsonic Wind Tunnel.

Comments: This series of tests studied the jet induced lift and pitching moment effects of two configurations in ground effect. The data includes surface pressures (delta wing only) and force and moment data. The moving ground belt was used. A series of forward velocities, nozzle pressure ratios, ground heights, and belt speeds were tested.

References: Wardwell,D.A.,Hange,C.E.,Kuhn,R.E.,Stewart,V.R.,"Jet-Induced Ground Effects on a Parametric Flat-Plate Model in Hover", NASA TM 104001, March 1993.

Kuhn,R.E.,Stewart,V.R., "Lift and Pitching Moment Induced on Jet STOVL Aircraft Hovering in Ground Effect - Data Report", WL-TR-93-3044, June 1993.

Stewart,V.R.,Kuhn,R.E. "Lift and Pitching Moment Induced on Jet STOVL Aircraft by the Ground Vortex - Data Report", WL-TR-93-3045, June 1993.

(DTIC Numbers: ADA 269816, 269700)

Data in Report?: Yes

Data available on Disk?: Yes

Industry Needs Questionnaire

Although not stated, I assume the class of vehicle being addressed in this workshop and by this questionnaire is a highly maneuverable fighter.

1. The single most important capability is robustness, the method should not fail or fail to give a result given a legal set of input. I know of very few programs that meet this criterion.

1a. Yes. Lift and drag are obviously first priority.

1b. Yes. If thrust vectoring is to be included as a control device, the induced effects should be considered since semi-empirical methods are available.

1c. $C_{L\alpha}$, $C_{m\alpha}$. These are automatic given 1a and 1b. Lateral-directional derivatives discussed below.

1d. $C_{n\beta}$ or $C_{n\beta,dyn}$ vs α yes, others not really needed. A good method would give the location and breadth of any positive $C_{l\beta}$ spike.

1e. Yes. This is very important for all axes, and critical for tailless or reduced tail designs. See above comments on thrust vectoring.

1f. Not for conceptual/preliminary design, although a case can be made for C_{lp} and for extremely unstable vehicles C_{mq}. $C_{n\Omega}$ and $C_{l\Omega}$ are important at high angles of attack, but I know of no method that can even predict the sign of $C_{n\Omega}$.

2. Subsonic and supersonic. Fairings for transonic OK. The emphasis should be subsonic.

3. No. These would require other data (weight, inertias) that may not be known, and are flight condition dependent. It is generally easy to meet MIL 1797 requirements at low angles of attack. The difficulty is at high alpha and at approach conditions for carrier landings.

4. No more than 5 to 10 minutes to generate a complete alpha sweep for one Mach number.

5. Basic Datcom type input. Two-dimensional vortex lattice type input okay if simple. Three-dimensional panel type models out of the question.

6. Do you have a design/synthesis tool in mind? Is it available for general use? A stand alone code is the logical first step.

7. Tabular output only, in a format that can be easily modified by the user. Everyone uses their own, unique Graphics tools.

8. No. This sounds good, but may not be worth the cost. A lot of effort was expended putting this into Missile Datcom, and I only know of one organization that uses it, out of over 150 users.

9. It depends on the level of analysis, and what the code will be capable of doing. Advanced features like nose vortex control devices or STOVL ground effects will require an empirical solution.

10. Mach, Reynolds, alpha and beta.
Forebody: smooth; chined; none
Canard: none; volume ($S_c l/S_w c$), height, AR, Λ, λ, Γ (if large)
Wing: straight, cranked, LEX, AR, Λ, λ, Γ (if large)
H. tail: none; volume, height, LEX, AR, Λ, λ, Γ (if large)
V. tail: none; number, volume, location, AR, Λ, ϕ
STOVL vehicles would have a set of propulsion parameters.

11. This depends on what parameter is to be predicted.

12. Wind tunnel data list attached. The generic rotary data (WRDC-TR-89-3090) and fighter data (WL-TR-91-3041) could be used for method development. The STOVL data base has already been used for development of an empirical method, WL-TR-93-3046 and 93-3061. The other data is configuration specific (F-15/SMTD, F-16/VISTA) and could probably only be used for validation.

13. Generic fighter, both canard and conventional, with smooth and chined forebodies if possible, and single, twin and tails on wing.

14. Lift and drag, 10-20%. Static margin, within 10%c. Control power within 20%.

15. Additional items in the needed capabilities definitely include high-lift devices. Depending on the configuration, ground effects and propulsion induced effects could be important (for STOVL, these are critical). Hinge and bending moments are also important, but not for conceptual design.

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Comments: Here are Boeing's Inputs to your survey. I regret we can not be present to participate in your discussions. I hope a Boeing rep will be there to give us some feed back on what is going on. Thanks

Attach Document At Line

standard_input

12/07/93 12:12 AM

Aircraft Conceptual Design Issues

** GENERAL COMMENTS **

1.) NASA needs to catalog and make available in some standardized machine readable format all of the windtunnel test data available. This should include Unclassified and any recently declassified data. It is important that sufficient geometry information be provided to allow the data to be utilized in the validation of prediction methods. (Parametric and Model Loft) There is truly a staggering amount of data available but the amount of effort required to identify and acquire data and methods is prohibitive.

2.) A considerable amount of work has been done and continues to be done in the area of prediction of aerodynamic characteristics in conceptual design. When problems are encountered we seem more inclined to start a new effort rather than grow and improve existing methods. Some of the reasons are maintainability of existing codes, and lack of knowlege in the availability and capabilities of existing codes. Another problem is lack of interest in improving old methods and the lure of "new" approaches. It is important to re-discover old methods and know how their limitations have eased as technology has improved.

3.) Most aerodynamic conceptual prediction methods are based on isolated components. This is not an accurate prediction for current configuration because of the highly swept blended wing body configurations have significant body lift and high levels of vorticity. Interactions between components can not be ignored. In addition, fighter aircraft are being pushed into the non-linear high angle-of-attack range primarly for agility. Some work has been done to predict leading edge effects but more work needs to be done to better understand the planform (including LEXs) and leading edge scaling effects with Reynolds Number. Trailing edge separation becomes important near and post stall and needs to also be addressed.

4.) Conceptual level Product of Inertia requires a large amount of configuration specific geometry and weights. It doesn't seem like it would take a great deal of effort to develop a prediction method simular to the moments of inertia that would be dependent of aircraft weight, high wing vs low wing, engine location, and the tail configuration. Without this capability, significant cross coupling effects would be ignored.

5.) Aerodynamic Center Variation with Angle-of-Attack and Mach Number predictions need to be developed for the conceptual level design. Downwash gradients with angle-of-attack should be included as well.

6.) Their seems to be a leap in weights estimates based on knowlege of the structural layout. Could a set of guidelines for leading and trailing edge spar locations, stringer spacing, etc be developed to allow improvements in the accuracy of wing weight estimation sensitivity to wing aspect ratio and elastic axis locations.

7.) The target computing platform for conceptual design methods should by the desktop computer because of the limited resources available to most new business activities. As of 12/1/93 it should be 486 level of capability. Don't forget that we are talking about methods suitable for accomplishing trade studies using multidisciplinary sizing/synthesis codes and not the single flight condition flow assessment of a fixed geometry with a flow solver.

8.) Seems like it may be time to investigate a combination of a simple panel model that uses emperically derived corrections. Use a combination of panel and emperial methods. Use emperical methods when adquate accuracy and better execution speed than a panel solution is achieved. The panel solutions should do a better job predicting interactions between the aircraft components. Ignore fillets a this stage of design. The simplified paneled geometry should be generated parametrically within the synthesis code for configuration trade studies. Output to a CAD system would be nice for Geometry verification. A simple vortex-lattice model, without modeling upper and lower surfaces separately, where thickness and leading edge radius effects are emperically modeled would be a good point of departure.

* Industry Needs Survey **

Methodology:

1.) The basic capability of the method should be the prediction of aerodynamic characteristics to 90 degrees angle-of-attack. This is justified by the fact that current fighter aircraft are today flying at these attitudes (Pugachev's pitch maneuver 12/6/93 Aviation week). Future fighters will fly in this flight regime more frequently as wing loading trends continue to go down, thrust-to-weight trends continue to increase, and pilots learn the tactics necessary to utilize the capability.

1a-1f) Aerodynamic Characteristics in all six degrees of freedom should be predicted. We can no longer accept tails sized to a constant volume coefficient when tail size should vary with the handling requirements, or agility requirements on a trade plot where wing loading, thrust-to-weight, aspect ratio are being traded. Compute the derrivatives necessary to address agility, maneuver, and handling qualities. The method must handle variations in wing planform, tails/canards, control surfaces, and forebody (LEX etc.).

2.) Design for VSTOL and Agility clearly require aerodynamic prediction in the high angle-of-attack, low speed portions of the envelope. Even Maneuver and takeoff/landing performance prediction will benifit for this capability. It is not clear that this capability is required beyond the

transonic flight regime. Concentrate on the speeds between best corner speed and stall.

3.) No, control surface sizing is really a geometry trade study and depends on the method used to optimize the configuration. The method developed to predict aerodynamic characteristics should compute aerodynamic characteristics assuming that the geometry is input. The synthestis code should have the capability to size tail/canard/control surfaces to meet handling qualities and agility requirements.

4.) This question is best anwsered by the phrase "the faster the better". It really comes down to a trade between acceptable accuracy and time it takes to conduct a trade study. It should be noted that a proper trade study should examine a large set of design requirements from a widely varying range of technologies to understand the combined sygenerstic effects. This implies that any future computational speed increases of the hardware will be offset by increasing the scope of the technologies in the model as well as improving the accuracy of the existing technology modules. The time it takes to run a sizing trade study should be kept down to half an hour on a 486 based desktop PC.

5.) The geometry input should be in the form of geometric parameters consistent with emperical methods. A spreadsheet style input driving a parametrically driven "crude loft" would be ideal. Again the issue involves a trade of minimizing time at the expense of accuracy. Keeping the number of inputs down is key.

) The method should consist of a toolkit of modules that can be integrated into existing analysis codes of be linked into a stand alone interactive tool.

7.) Output of the interactive system should be a plot file in "wind tunnel" data format and a IGES points file to feed into a CAD system. A simple graphics interface to allow plotting of the specified input geometry would be a good feature. It would be really "neat" if we could interface into MicroSoft Office using OLE2 and/or DLLs to input, run, document, plot, and store data.

8.) Scaling the model and analysis to windtunnel size or fullscale would ease the confusion of scaling effects. Nice but not required.

9.) Typically interactions between components or multiple panel surfaces would be better modeled using a simplified low order panel code while viscous effects are probably better handled using emperical methods.

Database:

10. Sweep, Aspect Ratio, forebody waterline, chine Vs round forebody, chine angle, leading edge radius, Tail location relative to wing.

11. Need at least 3 configurations with the same characteristics to establish the database for a given level of geometry characteristics.

12. Information for dozens of configutations exist, but not all of it is cataloged, most of it is available for inclusion (70%). About 80% exists on paper and 20% is electronic

Validataion:

13. Select 4 or 5 diverse configurations (planform, forebody, tails) that have detailed test data

14. Acceptable accuracy at the conceptual stage is typically 20%. Lift and drag should be about 5% in the linear range of the flight envelope and 20% in the non-linear range.

NONLINEAR AERO PREDICTION REQUIREMENTS WORKSHOP

Industry Needs Questionaire

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The following responses to the questionaire should be prefaced with the comment that NEAR has historically been a prediction method developer. The company is not a designer nor builder of flight vehicles; however, the company has recently consulted with a number of airframe organizations and produced aerodynamic characteristics for conceptual and preliminary design and analysis purposes. Much of this work has been accomplished pre-test and pre-flight.

Responses

Methodology:

1. Basic capabilities

The method should be able to produce the longitudinal and lateral aerodynamic characteristics over a wide range of flight conditions with only the geometry as input. The method should include separation and vortex-induced effects to produce overall forces and moments, component loads, and possibly pressure distributions. The flight conditions should include subsonic, transonic, and supersonic speeds and a reasonable range of both α and β.

1a. Yes, and as a function of Mach number also.

1b. Moment curves and trimmed polars are necessary for control system design and for flight simulations.

1c. Future flight vehicles which perform rapid maneuvers at high flow incidence angles will require all the basic stability derivatives for control system design and motion simulations. It is also important that the stability derivatives not be linearized, particularly in the high-α flow regimes. Derivatives with respect to control deflections are also important.

1d. Lateral-directional characteristics are essential for maneuvering high-α flight and for flight involving asymmetric control.

1e. Control power/effectiveness is particularly important at high angles of attack where wake effects can dictate the control capability of a tail fin. The ability to predict reasonable fin hinge moments is important for actuator design and control analysis.

1f. Dynamic derivatives are very important for maneuvering applications. The nonlinear method described above should be extendable into the dynamic regime, and at high angles of attack, the dynamic derivatives should not be linearized. Lateral dynamic derivatives should be considered by the method.

2. Speed regimes

All speed regimes from subsonic to hypersonic are important, but it is not necessary that a single method cover all regimes. There should be overlap of the different methods to assure continuity between speed regimes. Transonic speeds is particularly important.

3. Sizing capability

This is likely more interesting for optimization than for preliminary design and analysis. If a nonlinear aerodynamics method is available, sizing of components could either be added later, or it could be handled by a more specialized design method.

4. Run time, computational requirements, ...

The acceptable run time will depend on the phase of the design cycle. For conceptual design and early preliminary design analysis, 15 minutes for an angle of attack sweep on a workstation is reasonable. As the details of the calculation increase, so will the run time. The set up time is also important. For early results when the configuration is likely to change, the initial geometry set up and subsequent modifications should not take a significant amount of time, if they do, the method will not be used during the conceptual design phase.

After the overall geometry is defined, longer run times are probably more acceptable. Workstation runs of one or two hours may not be unreasonable, particularly if they can be accomplished overnight. Detailed flow field results for selected flow conditions may require multiple hours on a Cray, but if the geometry set up does not require weeks or months, this may be acceptable for special circumstances.

5. Form of geometry, set up time

The computational geometry should be available from a CAD system. In the early stages, it may be required that the geometry be specified by tabular input using simplified shapes so that preliminary aero performance estimates can be made quickly. In the conceptual and preliminary design period when changes are frequent, the shortest possible set up time is necessary. Initial geometry set up should not require more than one or two days, and modifications around this geometry should be made in a matter of one or two hours. As the geometry becomes fixed and higher level methods are used for more detailed results, then geometry set up can require a little more effort; however, for preliminary design studies, geometry set up should never be measured in man months.

6. Stand alone or part of design synthesis tool?

Both are desirable. In early design stages, the stand alone method is useful to look at aerodynamic characteristics without the coupling of other disciplines. After the first-order aerodynamics are acceptable, then the aero model can be considered as part of a design synthesis method.

For practical purposes, the design synthesis tool may require the use of simpler aero models which still represent the important nonlinear effects. Otherwise, the synthesis tool may be too difficult/expensive to use for preliminary design.

7. Output desired.

Engineers are going to want all levels of output; tabular, curves, graphics. It should be easy to integrate the early aero data with other disciplines, propulsion, controls, structures, etc. for their preliminary design efforts.

8. Integrate with known data and scale to configuration.

This is important, but it is possible it should be a separate step. Too much integration with the aero prediction method could blur the distinction between analytical and empirical results. This could make it difficult to evaluate the quality of the analytical information, and it could even lead to incorrect conclusions. The possibility of bad analytical results is just as likely as bad experimental results. Also, in the conceptual design stage, there may not be data available for a similar configuration under similar flow conditions.

9. Analytic solutions vs semi-empirical solutions.

Analytical methods are now reliable for attached flows and even for separation and vorticity dominated flows in some cases. However, for the near future, separation, transition, and turbulence will probably require semi-empirical information for practical design methods.

For dynamic information, it is very difficult to obtain semi-empirical information in ground-based testing, particularly where the time history of the motion is critical to the instantaneous results. For these cases, analytical methods may be the only alternative to study rapid maneuvers prior to flight tests.

Data Base:

10. Categorization parameters

The usual scaling parameters, M_∞, R_e, are important, but it is still not clear how turbulence is scaled between analysis, tests, and flight.

11. Data base components

The data base should consider the flow conditions of interest. Details on separation and transition locations are important. Component build up of the configuration is necessary, and measurements of forces and moments, pressures, and selected flow visualization are all necessary to evaluate the empirical information. Validation of the analytical methods with the experimental results is essential to understand both the analysis and the data.

12. Data available

NEAR has a data base of control fin data over a wide range of M_∞, α, ϕ, δ included in a prediction method M3F3CA (or MISL3). This code is proprietary, but the raw data are available in electronic form.

Validation:

13. Validation benchmark suite

For similar geometry and flow conditions, thorough validation requires overall forces and moments, component forces and moments, pressure distributions, flow visualization, and selected quantitative flow field measurements.

14. Level of accuracy

Depends on the vehicle and mission. In some preliminary design cases, ±10% is good enough. In other cases, ±1% is required to evaluate the performance gains.

Other Areas of Interest and Concern:

High angles of attack

Dynamic flight conditions, unsteady aerodynamics

Maneuvering simulations

Flow control devices

Non-traditional geometries

Michael R. Mendenhall
November 5, 1993

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NON-LINEAR AERO REQUIREMENTS WORKSHOP
DECEMBER 8-9, 1993
NASA LANGLEY RESEARCH CENTER

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The purpose of the Non-Linear Aero Prediction Requirements Workshop, held at NASA Langley Research Center on December 8-9, 1993, was to identify and articulate requirements for non-linear aero prediction capabilities during conceptual/preliminary design. The attendees included engineers from industry, government, and academia in a variety of aerospace disciplines, such as advanced design, aerodynamic performance analysis, aero methods development, flight controls, and experimental and theoretical aerodynamics. Presentations by industry and government organizations were followed by panel discussions. This report contains copies of the presentations and the results of the panel discussions.

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